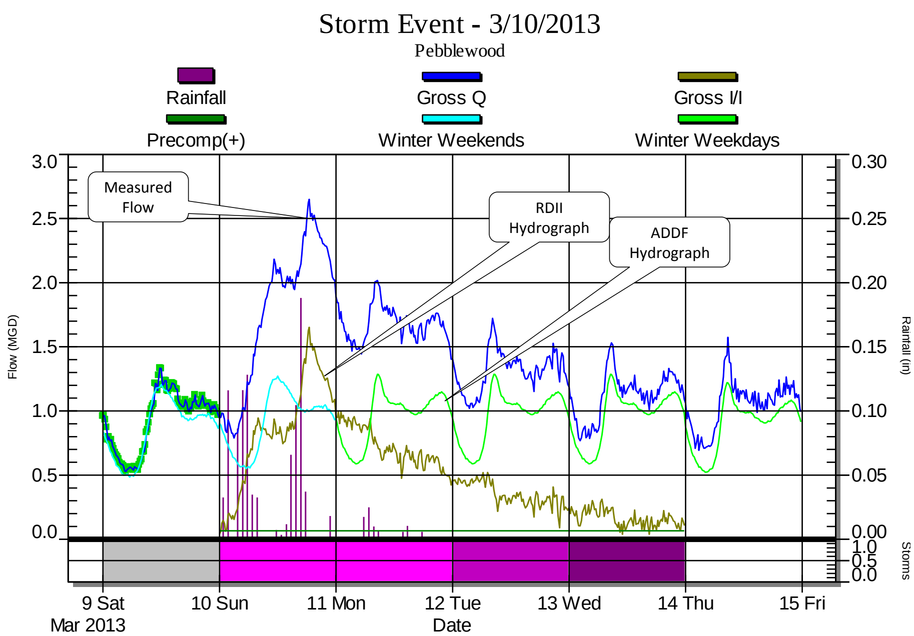
ADS ENVIRONMENTAL SERVICES

City of Naperville RDII Report and Flow Monitoring Results



ADS Environmental Services
2104

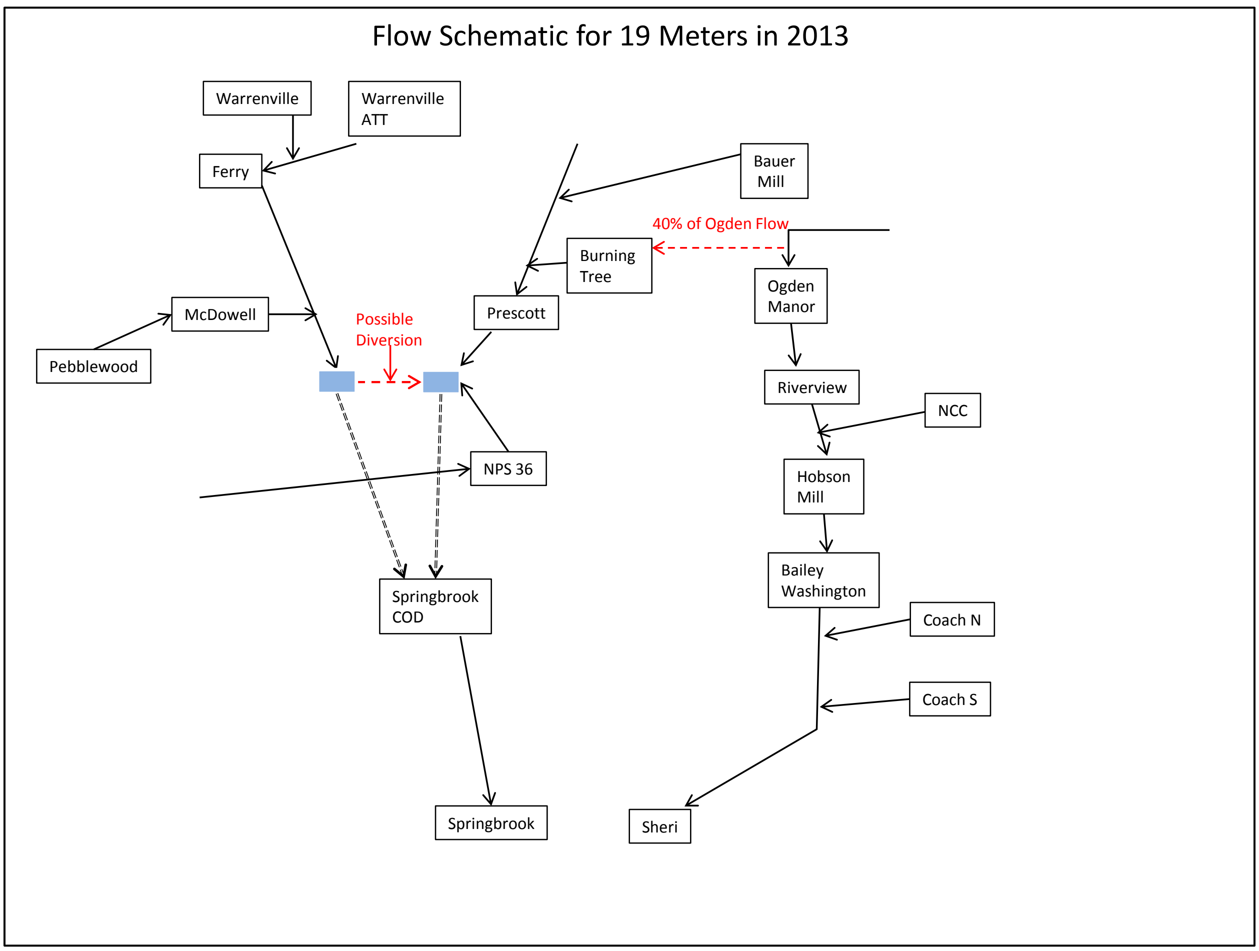
Table of Contents

Executive Summary

1.0 – Background

The City of Naperville operates a fleet of approximately 54 flow meters in permanent and temporary service. The City desires to conduct an analysis of Rainfall Dependent Infiltration Inflow (RDII) on its sewer system using 19 flow meters in permanent use. ADS was selected to perform this RDII analysis using Sliicer software and the results are posted on Sliicer.com for the City's use. Data from most of calendar year 2013 was selected for analysis and the data were provided by the City in a Profile data base. Figure 1 is a schematic of the metering network showing the flow pattern and approximate meter locations. In addition rainfall data were provided from nine rain gauges operated by the City.

Figure 1 Schematic of Meter Layout



The neighborhood sewer shed boundaries provided by the City were redrawn in GIS to reflect the actual flow patterns within each meter sewershed. Revised basin sizes in Acres and linear feet of public sewers were calculated. The new sewer shed boundaries are shown in Figure 2. There are private sewers in some of the meter sewershed and those sewers are not included in the total lengths.

Figure 2 Map of Sewer sheds from 19 flow meters.

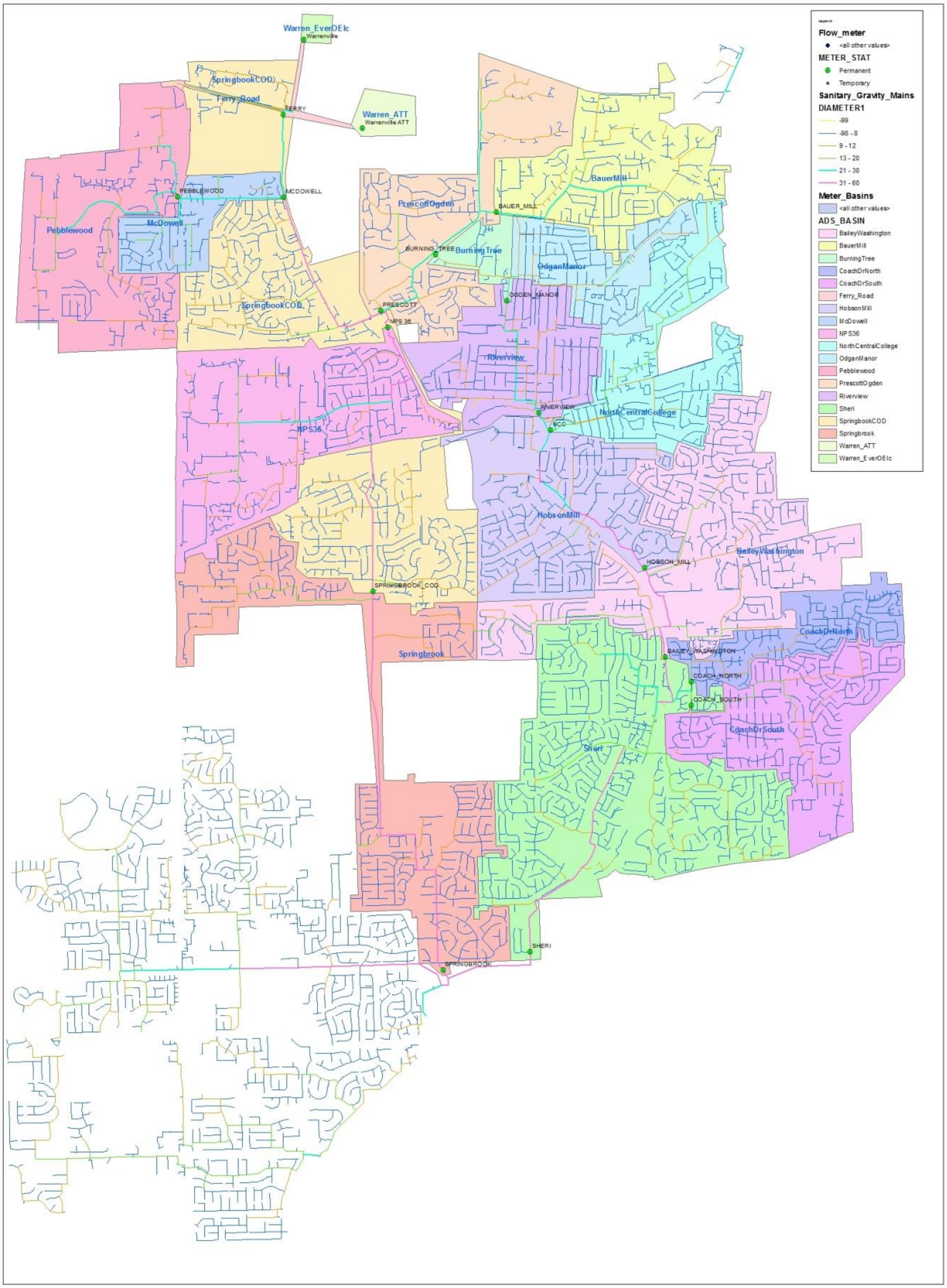


Table 1 Size of each metered sewer shed in Acres and LF.

	Actual Size		Consider Diversion	
Basin	Area	Length	Area	Length
BaileyWashington	1,837	222,585		
BauerMill	1,018	110,365		
BurningTree	152	12,599	377	82,857
CoachDrNorth	506	71,070		
CoachDrSouth	1,108	134,110		
Ferry_Road	99	30,193		
HobsonMill	1,264	151,369		
McDowell	381	49,521		
NorthCentralCollege	983	123,432		
NPS36	1,604	162,208		
OdganManor	563	70,258	338	42,155
Pebblewood	1,405	105,860		
PrescottOgden	1,166	108,630		
Riverview	852	111,452		
Sheri	2,513	318,672		
SpringbookCOD	2,631	264,743		
Springbrook	1,872	203,435		
Warren_ATT	999	99,999		
Warren_EverOElc	999	99,999		

In this report the terms 'sewer shed' and 'basin' are used interchangeably and have the same meaning. The basin sizes of the metered sewer sheds in Acres and Linear Feet of sewer are listed in Table 1. This table includes the length of public sewers. Values of multiple 9's are used when a proper value is not known. The reason to keep track of basin size is two-fold. The first use is to 'normalize' the flow measurements by basin size to produce and apples-to-apples comparison of RDII severity.

Secondly, the basin size has value in interpreting RDII severity. Large basins will exhibit RDII severity close to the system-wide average and small basin will exhibit RDII severity much higher and much lower than the system average. To compensate for the diversion that allows 40% of the flow from Ogden Manor to enter the Burning Tree sewer shed, 40% of the acres and LF of the Ogden Manor sewer shed are transferred to the Burning Tree sewer shed. The revised values are in the right two columns in Table 1.

1.1 – Objective and Strategy

The objective of this study was to evaluate the dry weather and wet weather performance of the metered portion of the Naperville Sanitary Sewer system through the period of 1 January through 8 November 2013 and especially during the large storm of 17 April.

Infiltration/Inflow (I/I) is a general term to describe any extraneous water entering a sewer from rainfall or from ground water. A more focused definition of I/I makes a distinction between Rainfall Dependent Infiltration Inflow (RDII) and Base Infiltration (BI). RDII is the flow appearing in sewers during and immediately after a rainfall and BI is the ground water entering the sewer on a steady or seasonal basis. In this report all calculations are for RDII, but the terms RDII and I/I are often used interchangeably. The analysis of the data for this report was conducted with the use of the ADS Sliicer software, which is an internal product. This project and the entire analysis are also available on the Internet on the Sliicer.com web site. The report is written by Patrick L. Stevens, P.E., Vice President of Engineering and Chris Skehan, Business development Manager of ADS Environmental Services.

Results

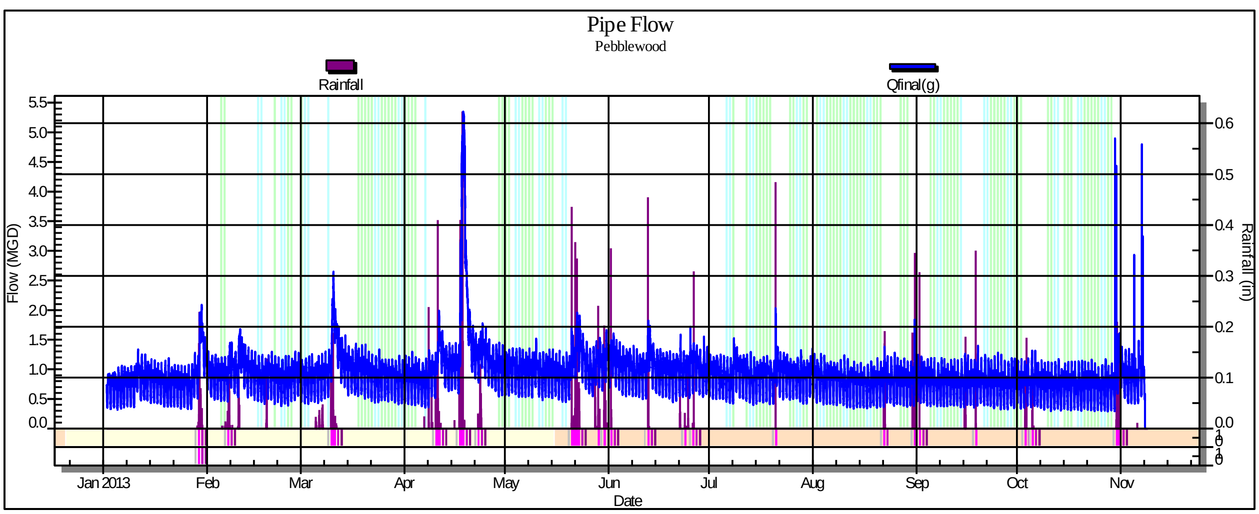
2.0 – Seasons and Dry Day Selections

Sewer systems behave differently in Winter and Summer seasons and the distinction between the two has much to do with whether vegetation is active or dormant. This analysis was divided into Winter and Summer seasons and we look at both dry weather and wet weather performance separately. The initial data through 15 May were considered to be winter or the period of dormant vegetation. Summer, or the period of active vegetation, began 16 May through the end of the study on 8 November. The last storm was 30 October, after a dry October and this storm was grouped into the Summer storms.

Figure 3 is overall view of the data used to conduct this analysis. The blue hydrograph is the flow data from Pebblewood for the entire period and the magenta hyetographs are the recorded rainfall from a blend of the City's nine rain gauges. The dry days selected for analysis are highlighted in green (weekdays) and blue (weekends) shaded bands. Storms of over ½ inch were selected for analysis and those 21 events are shown as magenta bands along the bottom of the hydrograph. More detailed figures will be shown in this report and discussed in the results section. This report will characterize both the Dry and Wet Weather performance of each of the 19 locations.

Unless specified otherwise, all data displays and values in this report are based on 15-minute time steps.

Figure 3 Flow hydrograph, rainfall hyetograph, selected dry days and storms for Pebblewood.

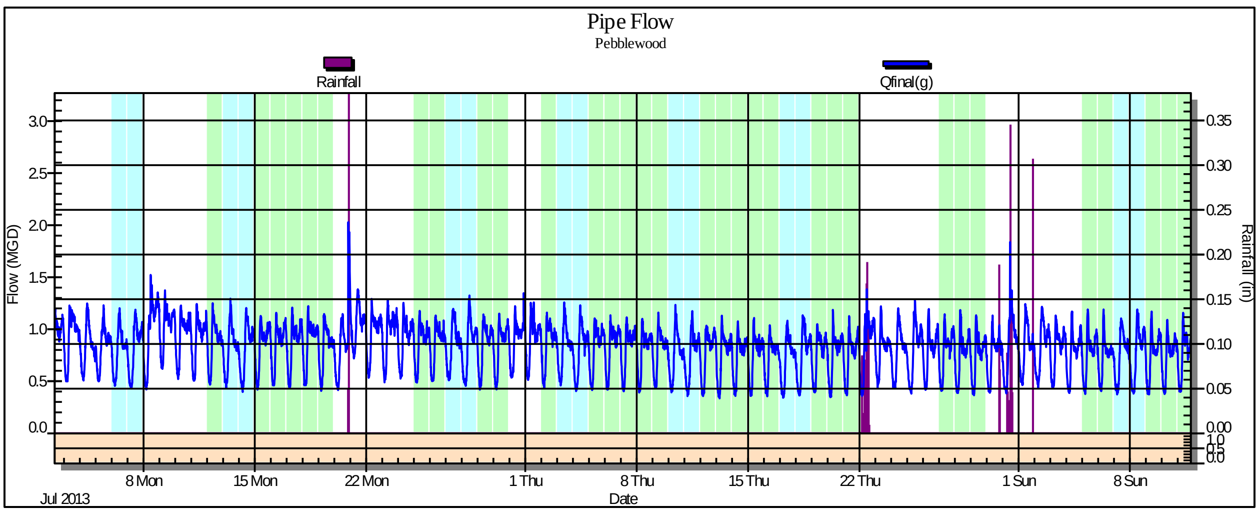


2.1 – Calculating Dry Day Information

One of the first steps in conducting an RDII analysis is to determine Average Dry Day Flow (ADDF) at each metering location and this information is used in two ways. The first is that the ADDF is subtracted from the flow measured during a storm and the difference is RDII. The second is that the shape of the ADDF hydrograph is used to estimate what portion of the ADDF is wastewater production (WWP) and what portion is base infiltration (BI).

Dry day flows are obtained by identifying days that are not influenced by previous rainfall and that have a regular diurnal (daily) pattern. In nearly all cases weekday and weekend diurnal patterns are different and are averaged separately. The selected days are averaged to generate separate weekday and weekend diurnal pattern. The hydrograph in Figure 4 displays the Pebblewood dry days that were selected in July and August with weekdays highlighted in green and weekends highlighted in blue.

Figure 4 – The Weekday Dry Days are highlighted in green and Weekend Dry Days in blue.



One can get a good idea about the magnitude of Base Infiltration by observing the size of the gap between zero the minimum flows. If no Base Infiltration existed, the minimum night-time flow would be close to zero (~15% of average daily flow) and the lower points on the blue hydrograph would be close to the bottom of the hydrograph. In Figure 4 the bottom of the blue hydrograph is close to 0.5 mgd. Later in the report the calculated Base Infiltration is shown to be ~ 1/3rd of the average flow.

Figure 5 displays all the summer weekday hydrographs in light green and all summer weekend hydrographs in light blue for Pebblewood and each set is averaged into the ADDF hydrographs for weekdays and weekends. The purpose of this graphic is to observe meter repeatability and look for unusual water use patterns in the basin. In this example there are 54 weekday traces and 27 weekend traces plotted together and this reflects both meter accuracy and repeatable flow patterns.

Figure 5 Average Weekday and Weekend Dry Days for Pebblewood.

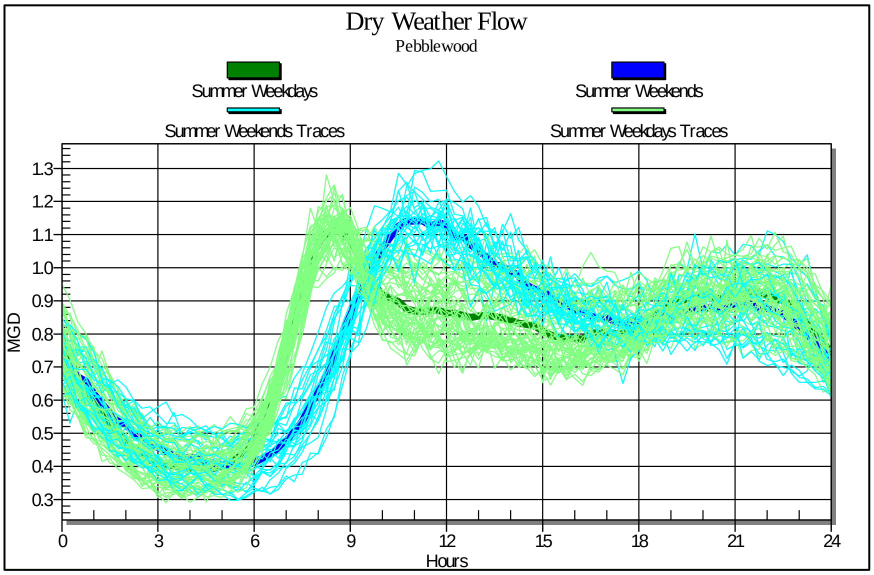
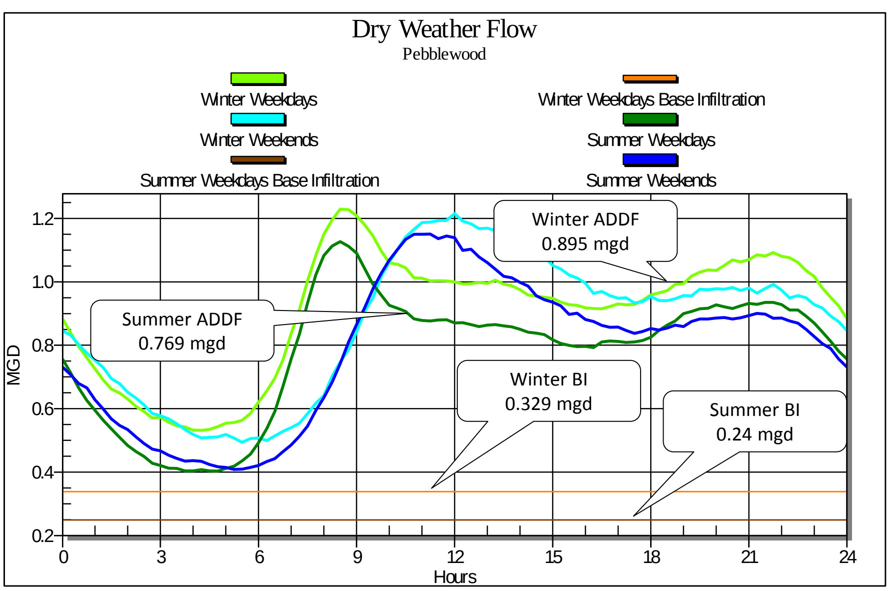


Figure 6 displays the two sets of ADDF curves for the winter and summer seasons for Pebblewood. The ADDF values are shown for the weekday average. The Slicer software also has four algorithms for estimating Base Infiltration (BI) based on the shape of the ADDF hydrograph. The estimates for winter and summer Base Infiltration (BI) are shown by the horizontal lines on the hydrograph.

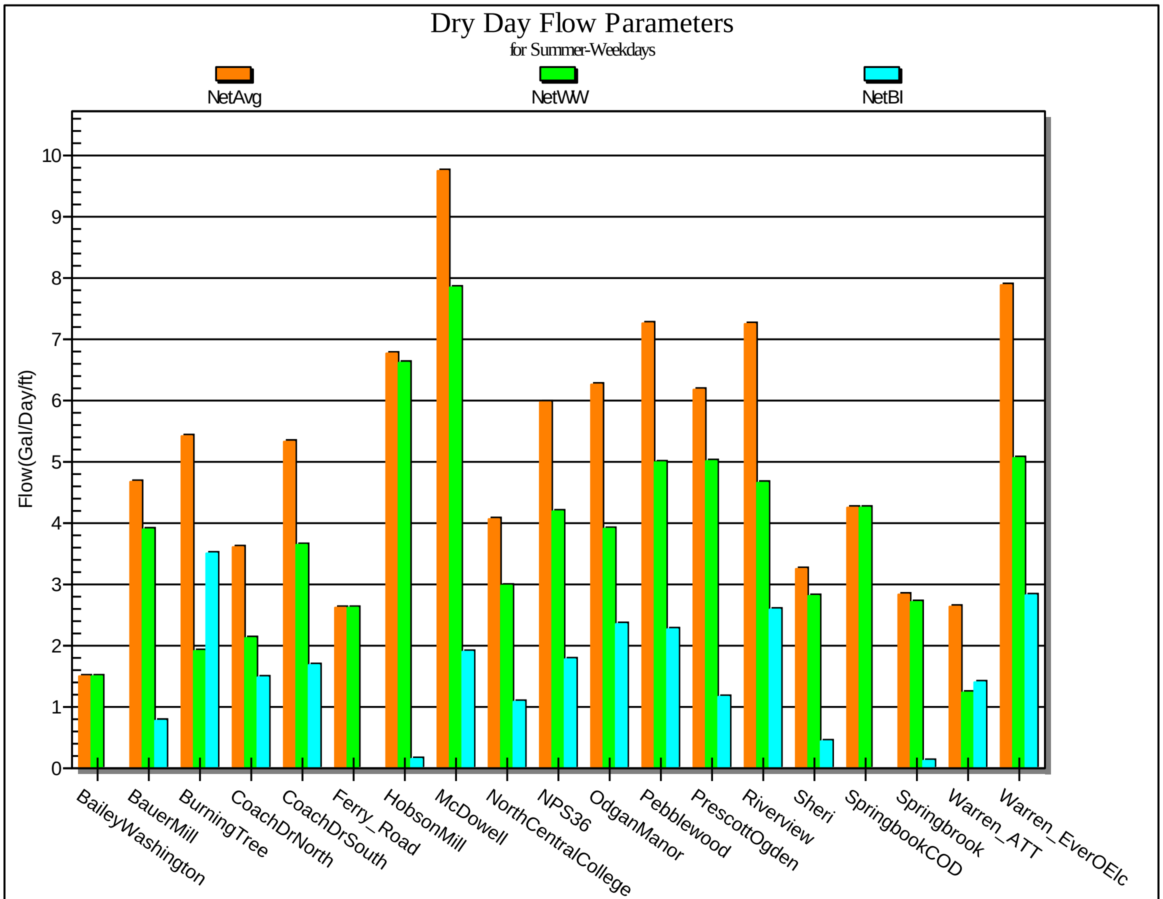
Figure 6 The average Weekend and Weekday hydrographs for both winter and summer.



The algorithms use to estimate Base Infiltration are designed to operate on small sewer sheds at the upper portions of a sewer network where a meter is directly measuring flow with no subtractions. The algorithms are less reliable when flows are measured further downstream on trunk sewers and when basins are defined by subtraction between trunk sewers. Also the travel time between trunk meters tends to distort the ADDF hydrograph and decreases the reliability of the BI estimates. This meter network has both types of meters deployed and the reader should apply less confidence to estimates of Wastewater Production (WWP) and Base Infiltration (BI) on the trunk sewer meters.

The term 'Net' in this report indicates that the value is the result of subtraction between meters. The Net ADDF, Net WWP and Net BI are normalized by the length of sewer in each basin to obtain an apples-to-apples comparison and these values are shown in Figure 7. The values are expressed in GPD/LF of public sewer. These values are a function of land use with medium-density residential sewersheds typically being in the range of 2 to 5 gpd/LF. Low density residential areas can produce less than 2 gpd/lf and high density residential (apartments) and business districts can be in the range of 7 to 10 gpd/LF. The larger the sewershed, the less likely there is to be a uniform land use.

Figure 7 ADDF values normalized by LF of sewer in each sewershed expressed in gpd/LF.



Basin	BaileyWashington	BauerMill	BurningTree	CoachDrNorth	CoachDrSouth	Ferry_Road	HobsonMill	McDowell	NorthCentralCollege	NPS36	OdganManor	Pebblewood	PrescottOgden	Riverview	Sheri	SpringbookCOD	Springbrook	Warren_ATT	Warren_EverOElc
NetAvg	1.502	4.675	5.420	3.608	5.330	2.619	6.769	9.748	4.066	5.971	6.262	7.262	6.178	7.250	3.253	4.253	2.836	2.637	7.887
NetWW	1.502	3.900	1.915	2.125	3.646	2.619	6.617	7.847	2.980	4.192	3.908	4.994	5.013	4.660	2.812	4.253	2.714	1.235	5.063
NetBI		0.776	3.505	1.483	1.683		0.152	1.901	1.085	1.779	2.354	2.268	1.165	2.590	0.440		0.121	1.402	2.824

There are at least two uses that can be made of the ADDF data in Figure 7. One is truth-telling step for the analyst. Values here that are outside of the normal range indicate that 1) the land use is not residential, 2) the LF of sewers is wrong, 3) there are problems with the meter data or the flow schematic (meter subtraction) is wrong. The Ferry Road and the two Warrenville sewersheds have 'dummy' values for sewer length so those values can be ignored. The Bailey Washington and McDowell meters/sewersheds are suspects that may require additional review.

The second use is to observe the relative value of BI (blue bar) to the value of the Wastewater Production (green bar). If they are close to equal that means that half the flow in the sewer is Base Infiltration. If the blue bar is small compared to the green bar it suggests that not much Base Infiltration exists in the sewer. The cautionary discussion on the previous pages suggests that this analysis begins to lose accuracy for downstream meters on trunk sewer. The analysis of the Sheri meter suggests that not much BI is entering the system between it and the three upstream meters. Don't place much credence on this analysis for downstream meters similar to Sheri. Nationally it has been estimated that 40% of the water treated in wastewater treatment plants is base infiltration.

Table 2 is a consolidated summary of the normalized ADDF values for weekdays for winter and summer seasons. Meter data did not exist for some this study period and that is the cause of zero values for NetAvg (ADDF). Figures 8 and 9 on the next two pages are maps of the sewersheds showing the New Wastewater Production (WWP) per LF of sewer for the Winter months and Summer months.

Table 2 Net ADDF values for winter and summer in gpd/LF.

	Winter Values gpd/LF			Summer Values gpd/LF		
Meter	NetAvg	NetWW	NetBI	NetAvg	NetWW	NetBI
BaileyWashington	1.3	1.3	0.0	1.5	1.5	0.0
BauerMill	4.8	3.9	1.0	4.7	3.9	0.8
BurningTree	0.0	0.0	0.0	5.4	1.9	3.5
CoachDrNorth	0.0	0.0	0.0	3.6	2.1	1.5
CoachDrSouth	5.9	3.8	2.0	5.3	3.6	1.7
Ferry_Road	1.8	1.8	0.0	2.6	2.6	0.0
HobsonMill	8.9	8.0	0.9	6.8	6.6	0.2
McDowell	10.9	6.1	4.8	9.7	7.8	1.9
NorthCentralCollege	0.0	0.0	0.0	4.1	3.0	1.1
NPS36	6.7	4.7	2.0	6.0	4.2	1.8
OdganManor	0.0	0.0	0.0	6.3	3.9	2.4
Pebblewood	8.5	5.3	3.1	7.3	5.0	2.3
PrescottOgden	9.2	5.2	4.0	6.2	5.0	1.2
Riverview	6.0	3.2	2.8	7.3	4.7	2.6
Sheri	5.5	4.4	1.1	3.3	2.8	0.4
SpringbookCOD	3.2	3.2	0.0	4.3	4.3	0.0
Springbrook	5.3	5.3	0.0	2.8	2.7	0.1
Warren_ATT	3.2	1.4	1.7	2.6	1.2	1.4
Warren_EverOElc	10.2	5.7	4.5	7.9	5.1	2.8

Figure 8 Map of ADDF in Winter months in gpd/LF

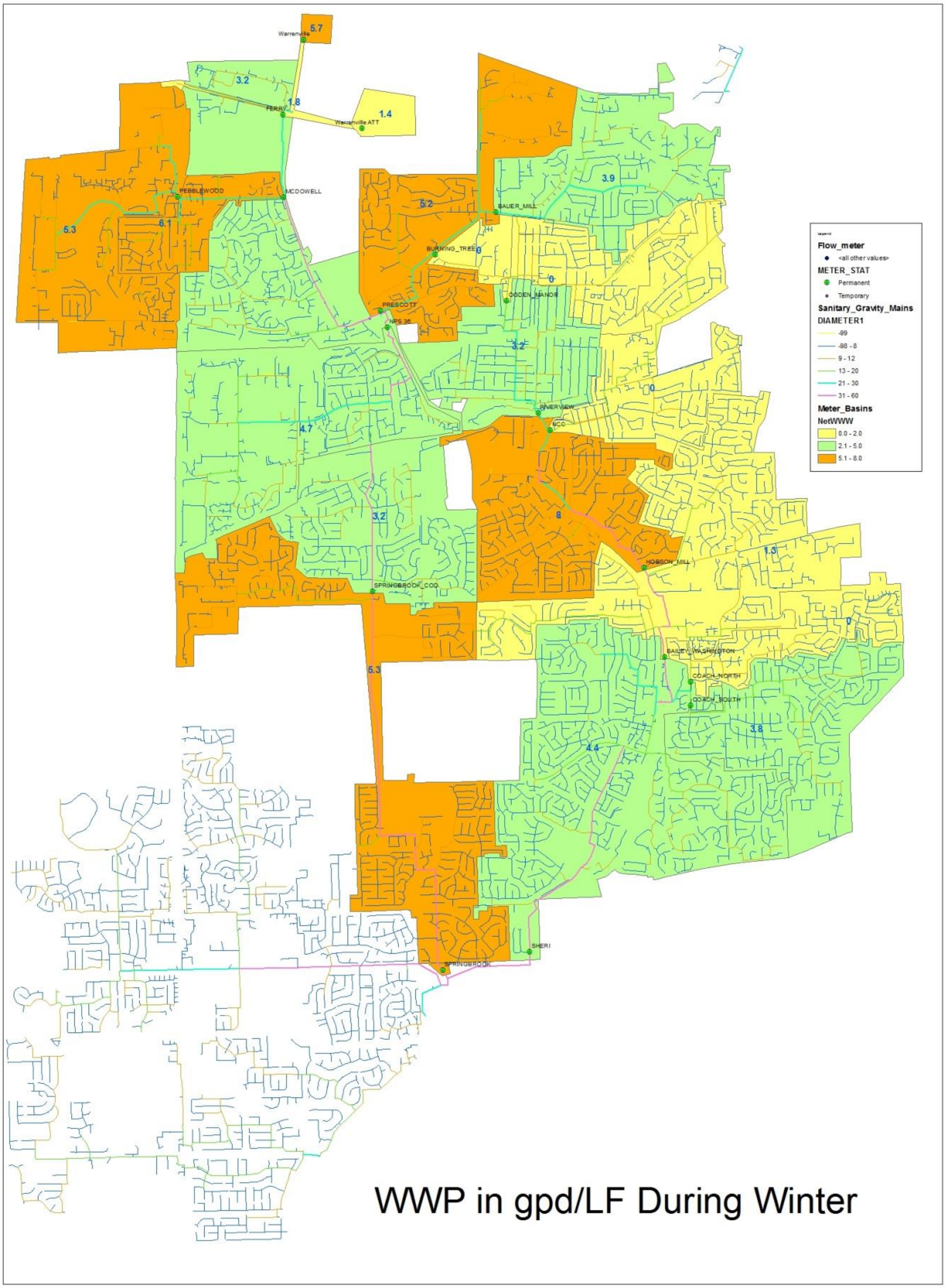
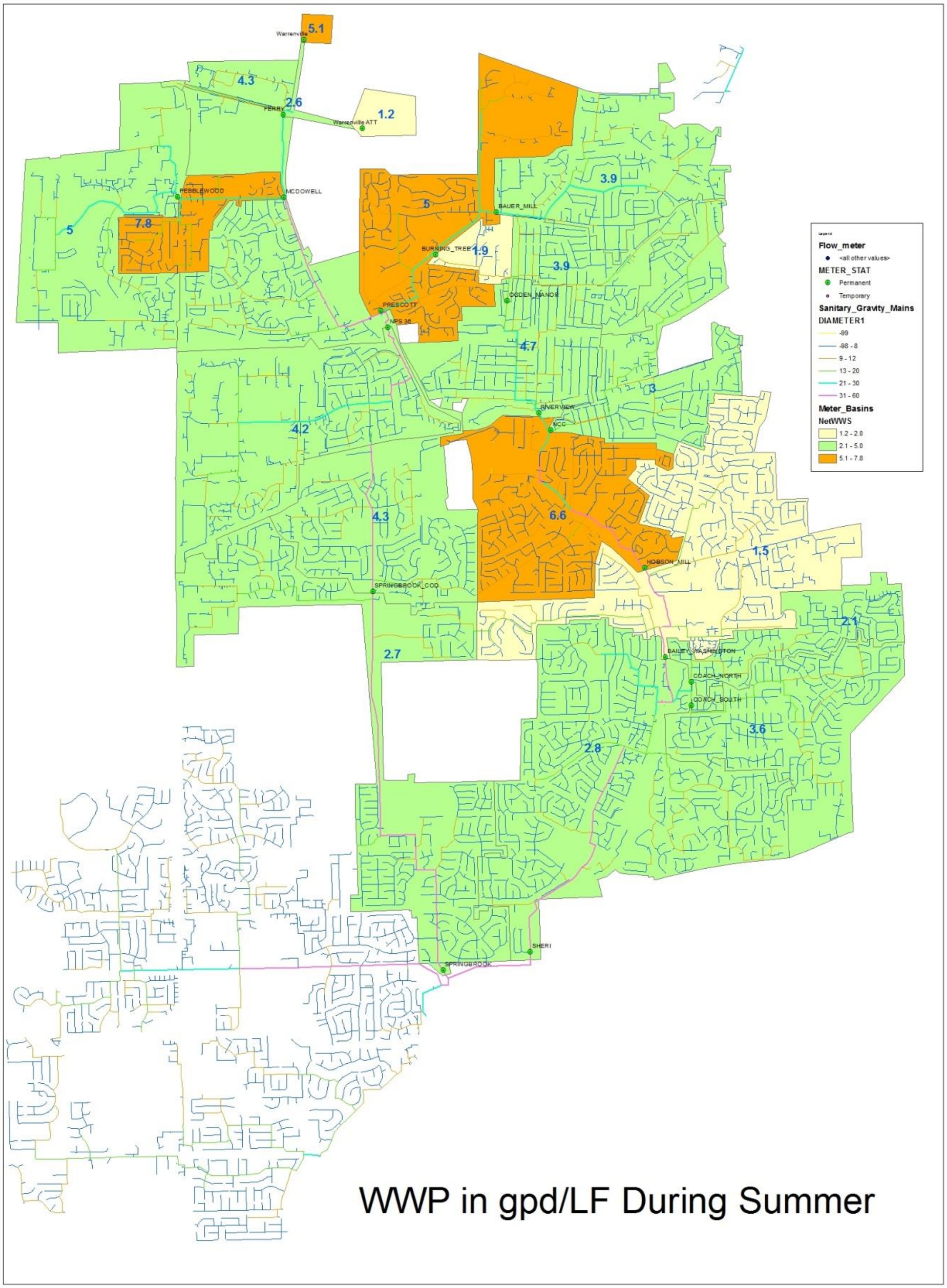


Figure 9 Map of ADDF during Summer months in gpd/LF of sewers



2.2 - Rainfall Analysis

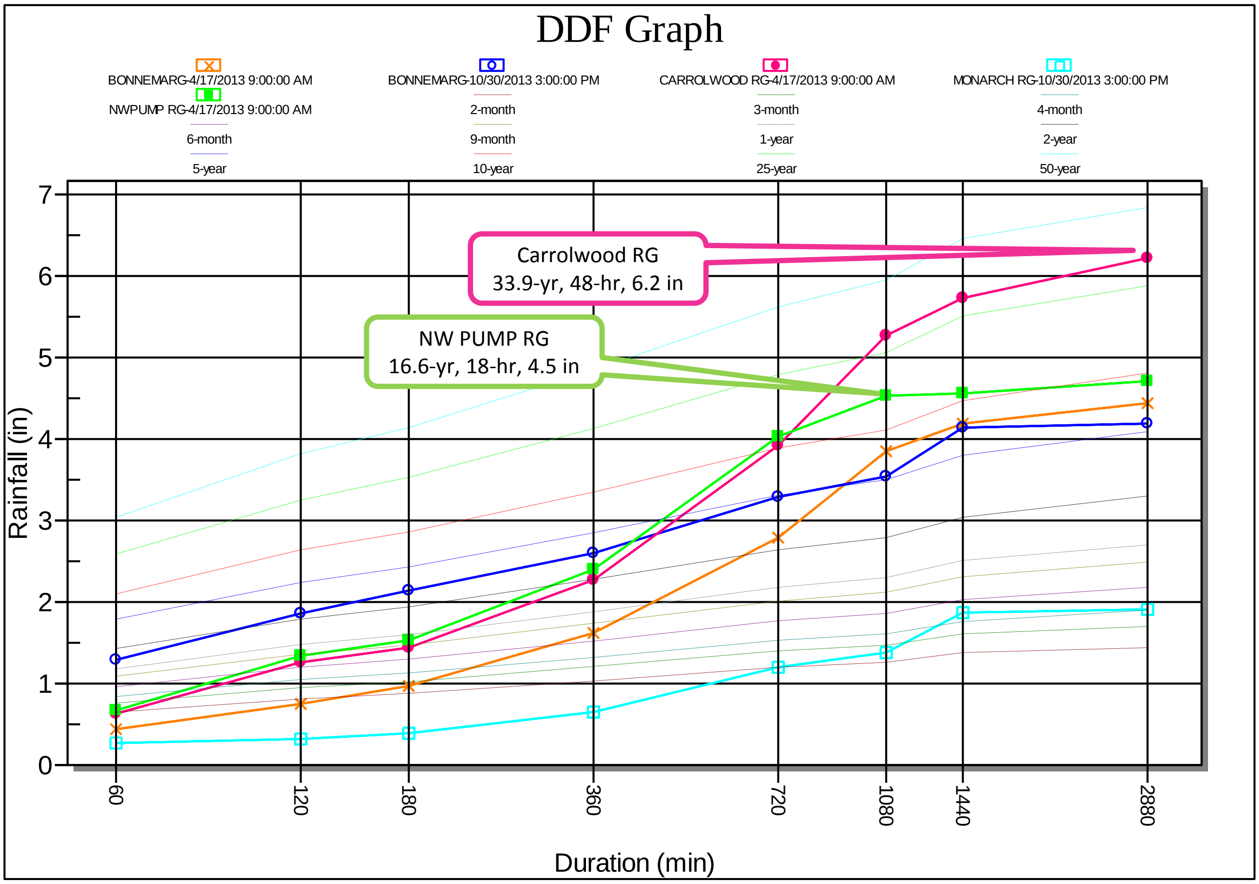
This rainfall analysis will look at the total rainfall recorded by each rain gauge for each storm and also at the maximum return frequency for each rain gauge and each storm. Table 3 lists the measured rainfall for each of the nine rain gauges. The NW Pump RG appears to underreport rainfall and the total for the period was around half the other gauges that operated for all storms. For the 30 October storm, it was assumed that the data from this gauge were not valid and rainfall was calculated from the next closest rain gauges.

Table 3 Total rainfall measured in inches by each rain gauge for each storm.

	Rainfall in Inches recorded at each rain gauge								
Storm	BONNEMARG	CARROLWOOD RG	CENTURY RG	MONARCH RG	NWPUMP RG	SOC RG	SPRINGBROOK RG	SUMMERFIELD RG	SWPUMP RG
1/29/2013	1.79	1.79	1.55	1.44	0.89	1.41	0	1.51	1.63
2/7/2013	0.84	0.8	0.71	0.75	0.66	0.83	0	0.67	0.84
3/10/2013	1.27	1.22	1.3	1.02	1.06	1.3	0	1.14	1.25
4/10/2013	1.57	1.02	0.92	1.14	0.35	1.58	0	1.11	1.69
4/17/2013	4.44	6.22	5.73	6.13	4.71	6.73	0	6.64	6.36
4/22/2013	0.07	0.55	0.87	0.78	0.74	0.75	0	0.7	0.87
5/20/2013	0.75	2.86	3.28	2.11	1.25	3.42	2.63	2.41	2.63
5/28/2013	1.79	0.52	0.51	0.16	0.26	1.51	1.19	0.75	1.31
5/30/2013	1.09	0.56	0.35	0.28	0.41	0.91	0.73	0.5	1.13
6/1/2013	0.42	0.96	0.74	0	0.33	0.59	0.27	0.72	0.3
6/12/2013	1.72	1.83	1.06	0	0.42	1.73	1.74	1.83	2.26
6/23/2013	1.02	0.15	0.19	0.02	0.1	0.56	0.45	0.33	0.47
6/26/2013	4.44	0.34	0.35	0.01	0.22	0.63	0.49	0.56	0.6
7/20/2013	0.61	0.13	0	0	0.62	0.97	0.03	0.08	0
8/22/2013	1.22	1.1	0.01	0.02	0.74	1.18	0.63	1.03	1.41
8/31/2013	0.3	0.75	1.65	0.81	0.51	0.49	0.35	0.57	0.35
9/1/2013	0.04	0.02	0.65	0.47	0.09	0.05	0	0	0.35
9/18/2013	0.63	0.28	0.44	0.51	0.23	0.51	0.35	0.44	0.46
10/3/2013	0.51	0.48	0.53	0.28	0.27	0.72	0.47	0.53	0.73
10/5/2013	1.26	0.33	0.37	0.08	0.24	0.51	0	0	0.01
10/30/2013	4.19	2.7	2.33	1.91	0.74	3.39	3.22	2.85	3.95
Total	29.97	24.61	23.54	17.92	14.84	29.77	12.55	24.37	28.6

The ADS Sliicer software includes several powerful analysis tools to analyze and understand the rainfall measured in an RDII study. It allows the user to view hyetographs of multiple rain gauges to spot poor data. It allows user to ignore a RG for selected days and automatically recalculates a new rainfall distribution from the remaining RGs. It allows for four geographic distribution methods, such as Inverse Distance Squared, and handles radar rainfall input. Users can generate Depth Duration Frequency (DDF) (Figure 10) curves for the local area and plots individual storms as 'Worm Tracks' to determine return frequencies of each storm and each rain gauge. The maximum return frequency for any storm is listed in Table 4.

Figure 10 Depth Duration Frequency data plotted with 'Worm Tracks' for selected RG data.



It is easy to look at Figure 10 with a time scale on the bottom and conclude that this traces the storm history. But it is actually showing the maximum rainfall depth for each of the durations. The peak 120 minute rainfall depth can occur at the beginning, middle or end of the storm.

Table 4 Maximum Return Frequency for Each RG and Each Storm. Yellow storms exceeded a one-year return frequency.

	Maximum return frequency and duration for each raingauge								
Storm	BONNEMARG	CARROLWOOD RG	CENTURY RG	MONARCH RG	NWPUMP RG	SOC RG	SPRINGBROOK RG	SUMMERFIELD RG	SWPUMP RG
1/29/2013	3.9-mo;24-hr;1.8-in	4.2-mo;18-hr;1.6-in	2.6-mo;24-hr;1.5-in	2.3-mo;18-hr;1.3-in	1.3-mo;24-hr;0.9-in	2.1-mo;24-hr;1.4-in		2.4-mo;24-hr;1.5-in	2.9-mo;24-hr;1.6-in
2/7/2013	1.2-mo;12-hr;0.7-in	1.3-mo;12-hr;0.8-in	1.2-mo;6-hr;0.6-in	1.2-mo;18-hr;0.7-in	1.1-mo;12-hr;0.6-in	1.3-mo;18-hr;0.8-in		1.0-mo;18-hr;0.6-in	1.3-mo;18-hr;0.8-in
3/10/2013	1.8-mo;18-hr;1.1-in	1.7-mo;18-hr;1.1-in	1.9-mo;18-hr;1.2-in	1.5-mo;18-hr;0.9-in	1.5-mo;18-hr;1.0-in	1.9-mo;18-hr;1.2-in		1.7-mo;18-hr;1.0-in	1.9-mo;18-hr;1.2-in
4/10/2013	3.0-mo;18-hr;1.5-in	1.6-mo;1-hr;0.5-in	1.5-mo;1-hr;0.5-in	1.8-mo;2-hr;0.7-in	0.5-mo;48-hr;0.4-in	3.1-mo;18-hr;1.5-in		1.7-mo;1-hr;0.5-in	3.9-mo;18-hr;1.6-in
4/17/2013	7.9-yr;24-hr;4.2-in	33.9-yr;48-hr;6.2-in	25.6-yr;18-hr;5.1-in	35.1-yr;18-hr;5.4-in	16.6-yr;18-hr;4.5-in	59.3-yr;18-hr;6.1-in		49.2-yr;18-hr;5.9-in	49.4-yr;18-hr;5.9-in
4/22/2013	0.1-mo;12-hr;0.1-in	0.8-mo;12-hr;0.5-in	1.3-mo;12-hr;0.8-in	1.2-mo;12-hr;0.7-in	1.1-mo;12-hr;0.7-in	1.1-mo;24-hr;0.7-in		1.0-mo;12-hr;0.6-in	1.3-mo;18-hr;0.8-in
5/20/2013	1.0-mo;48-hr;0.7-in	1.1-yr;48-hr;2.7-in	4.8-yr;1-hr;1.8-in	4.6-mo;72-hr;2.1-in	1.6-mo;72-hr;1.3-in	4.1-yr;1-hr;1.7-in	2.8-yr;1-hr;1.5-in	1.2-yr;1-hr;1.2-in	3.7-yr;1-hr;1.6-in
5/28/2013	2.9-yr;1-hr;1.5-in	1.4-mo;1-hr;0.4-in	1.3-mo;1-hr;0.4-in	0.3-mo;12-hr;0.2-in	0.6-mo;1-hr;0.2-in	1.8-yr;1-hr;1.4-in	8.4-mo;1-hr;1.1-in	2.3-mo;1-hr;0.7-in	7.8-mo;1-hr;1.0-in
5/30/2013	1.8-mo;12-hr;1.1-in	0.9-mo;12-hr;0.5-in	0.6-mo;12-hr;0.3-in	0.4-mo;48-hr;0.3-in	0.8-mo;1-hr;0.3-in	1.5-mo;12-hr;0.9-in	1.3-mo;6-hr;0.6-in	0.7-mo;24-hr;0.5-in	1.7-mo;6-hr;0.9-in
6/1/2013	0.9-mo;3-hr;0.4-in	4.8-mo;1-hr;0.9-in	1.4-mo;6-hr;0.7-in		0.9-mo;1-hr;0.3-in	1.2-mo;1-hr;0.4-in	0.6-mo;1-hr;0.2-in	1.9-mo;1-hr;0.6-in	0.8-mo;1-hr;0.3-in
6/12/2013	10.4-mo;3-hr;1.5-in	11.5-mo;3-hr;1.6-in	2.6-mo;3-hr;1.0-in		0.9-mo;1-hr;0.3-in	9.2-mo;3-hr;1.5-in	9.2-mo;3-hr;1.5-in	10.7-mo;6-hr;1.8-in	1.9-yr;3-hr;1.9-in
6/23/2013	2.4-mo;1-hr;0.7-in	0.3-mo;2-hr;0.1-in	0.3-mo;2-hr;0.1-in	0.0-mo;18-hr;0.0-in	0.2-mo;3-hr;0.1-in	0.9-mo;1-hr;0.3-in	1.0-mo;1-hr;0.3-in	0.8-mo;1-hr;0.3-in	1.1-mo;1-hr;0.4-in
6/26/2013	18.5-yr;12-hr;4.4-in	1.0-mo;1-hr;0.3-in	0.5-mo;18-hr;0.3-in	0.0-mo;1-hr;0.0-in	0.7-mo;1-hr;0.2-in	1.4-mo;1-hr;0.5-in	1.3-mo;1-hr;0.4-in	1.6-mo;1-hr;0.5-in	1.4-mo;1-hr;0.5-in
7/20/2013	1.9-mo;1-hr;0.6-in	0.4-mo;1-hr;0.1-in			1.7-mo;1-hr;0.6-in	6.2-mo;1-hr;1.0-in	0.1-mo;2-hr;0.0-in	0.2-mo;1-hr;0.1-in	
8/22/2013	2.1-mo;12-hr;1.2-in	1.8-mo;12-hr;1.1-in	0.0-mo;1-hr;0.0-in	0.0-mo;18-hr;0.0-in	1.2-mo;12-hr;0.7-in	2.0-mo;12-hr;1.2-in	1.8-mo;1-hr;0.6-in	1.7-mo;12-hr;1.0-in	3.1-mo;12-hr;1.4-in
8/31/2013	0.8-mo;1-hr;0.3-in	1.9-mo;1-hr;0.6-in	5.0-mo;12-hr;1.6-in	1.5-mo;1-hr;0.5-in	0.8-mo;12-hr;0.5-in	1.3-mo;1-hr;0.4-in	0.9-mo;1-hr;0.3-in	1.6-mo;1-hr;0.5-in	0.8-mo;2-hr;0.3-in
9/1/2013	0.1-mo;2-hr;0.0-in	0.1-mo;1-hr;0.0-in	2.0-mo;1-hr;0.6-in	1.4-mo;1-hr;0.5-in	0.3-mo;1-hr;0.1-in	0.1-mo;2-hr;0.0-in	0.0-mo;1-hr;0.0-in		0.9-mo;1-hr;0.3-in
9/18/2013	1.4-mo;3-hr;0.6-in	0.7-mo;2-hr;0.3-in	1.0-mo;2-hr;0.4-in	1.4-mo;1-hr;0.5-in	0.5-mo;2-hr;0.2-in	1.2-mo;1-hr;0.4-in	0.8-mo;2-hr;0.3-in	1.2-mo;1-hr;0.4-in	1.2-mo;1-hr;0.4-in
10/3/2013	1.0-mo;1-hr;0.3-in	0.9-mo;1-hr;0.3-in	1.1-mo;1-hr;0.4-in	0.5-mo;12-hr;0.3-in	0.4-mo;12-hr;0.3-in	1.7-mo;1-hr;0.6-in	1.0-mo;1-hr;0.3-in	1.2-mo;1-hr;0.4-in	1.5-mo;1-hr;0.5-in
10/5/2013	1.1-yr;1-hr;1.2-in	1.0-mo;1-hr;0.3-in	0.9-mo;2-hr;0.4-in	0.2-mo;1-hr;0.1-in	0.7-mo;1-hr;0.2-in	1.5-mo;1-hr;0.5-in	0.0-mo;1-hr;0.0-in		0.0-mo;1-hr;0.0-in
10/30/2013	7.5-yr;24-hr;4.1-in	1.3-yr;24-hr;2.7-in	8.3-mo;24-hr;2.2-in	4.8-mo;24-hr;1.9-in	1.3-mo;6-hr;0.7-in	3.2-yr;24-hr;3.3-in	2.7-yr;24-hr;3.2-in	1.4-yr;24-hr;2.7-in	5.7-yr;24-hr;3.9-in

Rainfall on each basin is calculated using data from nearby rain gauges. The Inverse Squared weighting system was used to assign weights from each gauge to each sewershed and the weights are listed in Table 5. The nearest gauges have the highest weight.

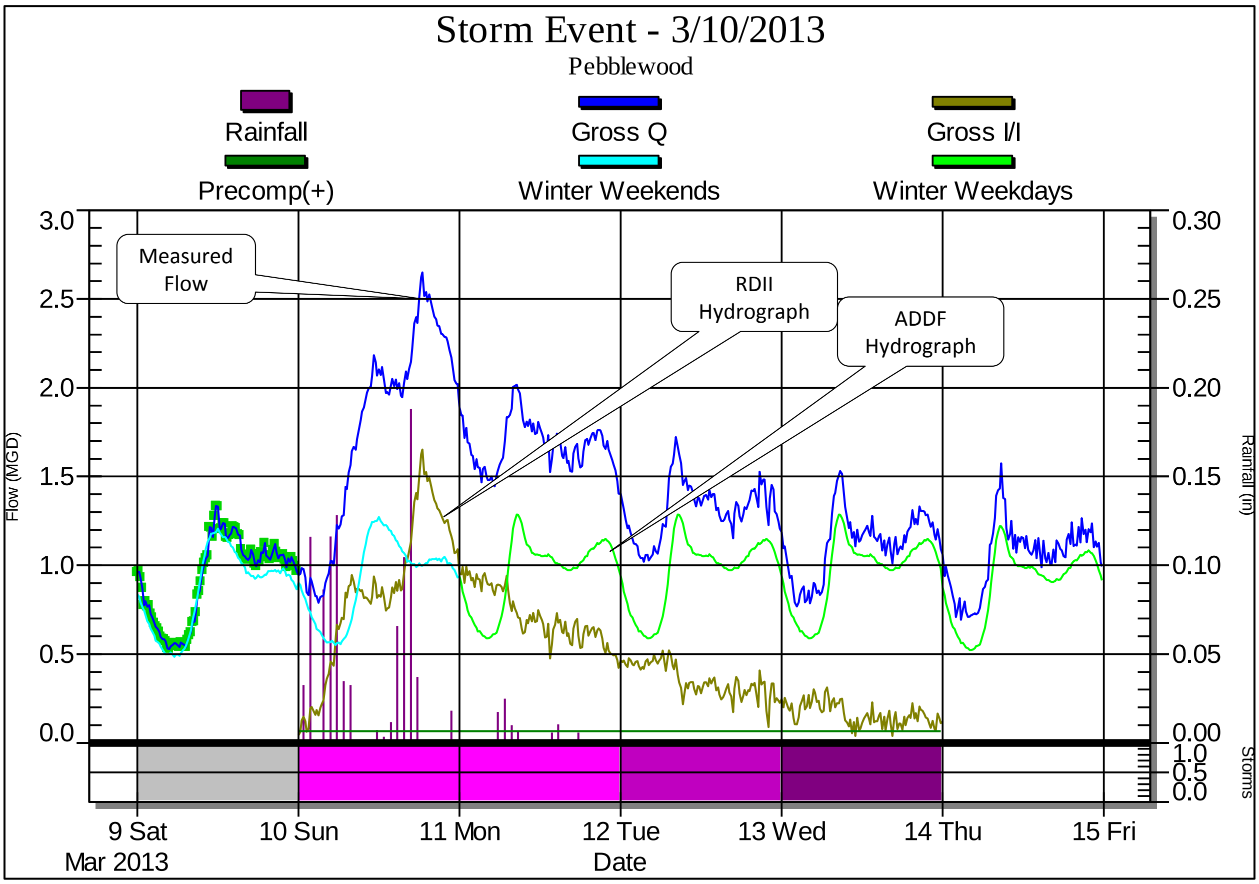
Table 5 Raingauge Weights used to calculate rainfall on each sewershed.

	Raingauge Weights for each Sewershed based on the Inverse Distance Squared Method								
BASIN	BONNEMORG	CARROLWOODRG	CENTURY RG	MONARCH RG	NWPUMP RG	SOC RG	SPRINGBROOK RG	SUMMERFIELD RG	SWPUMP RG
BaileyWashington	8	4	8	1	4	67	3	3	2
BauerMill	4	8	40	13	20	7	3	4	2
BurningTree	3	10	15	13	47	5	2	4	1
CoachDrNorth	29	3	10	1	3	46	3	3	2
CoachDrSouth	58	2	4	1	2	29	2	2	1
Ferry_Road	0	0	0	98	1	0	0	0	0
HobsonMill	8	11	21	4	15	26	5	7	3
McDowell	1	13	3	42	31	2	2	4	1
NorthCentralCollege	2	2	84	2	4	4	1	1	1
NPS36	1	50	2	3	35	2	1	4	1
OdganManor	3	10	21	10	40	6	2	4	2
Pebblewood	2	16	4	43	24	3	2	5	2
PrescottOgden	2	9	11	18	49	4	2	3	1
Riverview	4	11	25	7	34	9	3	5	2
Sheri	14	5	4	1	3	44	16	8	5
SpringbookCOD	3	39	6	4	21	9	4	13	2
Springbrook	3	30	4	3	11	7	3	38	2
Warren_ATT	0	0	0	100	0	0	0	0	0
Warren_EverOElc	0	0	0	100	0	0	0	0	0

2.3 - RDII Analysis – Storm-by-Storm

Sliicer.com calculates RDII at each meter site and if there are upstream meters, the Net RDII volume is calculated. Figure 11 is the storm hydrograph from Pebblewood from the 10 March 2013 storm. Included on the hydrograph are the rainfall hyetograph, ADDF Hydrograph, Metered Storm Flow and the RDIII hydrograph. A graphic like this is produced for each storm and each meter so users can evaluate the calculations. The graphics are in the Appendix.

Figure 11 Example of RDII hydrograph from Pebblewood



Larger basins (serwersheds) will naturally produce more RDII than smaller basins, so a normalization step is needed to evaluate sewersheds on an apples-to-apples basis. RDII is normalized by the combination of basin size and rainfall. Since we have basin size expressed in both acres and LF of sewer we typically want to normalize RDII both by area of the basin and by the length of sewer in the basin. When normalized by sewer length the result is expressed in Gallons per LF of sewer per inch of rainfall. When normalized by acres the result is expressed as a Capture Coefficient, which is the percentage of rainfall that enters the sewer as RDII.

Table 6 lists the normalized results for the six largest storms for the 16 valid sewer sheds. The Ferry Road and the two Warrenville sites are not included because the basin sizes are unknown. The sewersheds are ranked on the Average RDII severity for all six storms. An ‘n/a’ in this table indicates that the RDII calculation was either not made due to missing data or invalid for that storm.

The top four sewersheds are same on both lists and there are shifts in ranking below them that are likely due to differences in LF and acreage. For large basin like these we would generally place more credence on the ranking by LF of sewer because the ranking is not influenced by non-sewered areas such as athletic fields, parks, etc. The top four or five basins exhibit sufficient RDII severity to warrant additional investigation.

Table 6 Sewersheds Ranked by Severity. Ranking is by Normalized RDII in Gal/LF/Inch and Capture Coefficient.

	Sewersheds Ranked by Severity of both Gal/LF/inch and Capture Coefficient															
	Net RDII VolumeEvent Gal/LF/Inch									Capture Coefficent - Percent of rainfall entering sewer as RDII						
Storm	1/29/13	4/17/13	5/20/13	6/12/13	8/22/13	10/30/13	Avg			1/29/13	4/17/13	5/20/13	6/12/13	8/22/13	10/30/13	Avg
McDowell	20.9	22.3	25.5	12.4	5.0	8.3	15.7		McDowell	10	10.6	12.2	5.9	2.3	3.95	7.5
NPS36	17.6	22.2	19.3	18.1	3.8	11.1	15.3		NPS36	6.5	8.2	7.2	6.7	1.4	4.1	5.7
Riverview	13.1	18.9	11.7	7.9	3.5	6.9	10.3		Riverview	6.2	9	5.6	3.7	1.69	3.3	4.9
HobsonMill	13.6	n/a	11.6	8.9	2.4	6.6	8.6		HobsonMill	6.1	n/a	5.2	4	1	2.9	3.8
CoachDrSouth	13.2	5.2	6.6	7.0	n/a	5.8	7.5		CoachDrSouth	5.8	2.3	2.9	3.1	n/a	2.6	3.3
Pebblewood	9.4	11.1	8.6	6.5	1.9	5.0	7.1		OdganManor	n/a	n/a	n/a	n/a	1.2	4.1	2.7
OdganManor	n/a	n/a	n/a	n/a	2.8	9.0	5.9		NorthCentralCollege	n/a	n/a	n/a	n/a	0.7	3.8	2.3
Springbrook	15.9	2.6	4.6	4.7	1.8	3.6	5.5		Springbrook	6.35	1	1.7	1.8	0.72	1.4	2.2
BauerMill	9.0	7.9	5.9	1.6	2.8	5.0	5.4		BauerMill	3.6	3.1	2.3	0.6	1.1	2.0	2.1
NorthCentralCollege	n/a	n/a	n/a	n/a	1.6	8.0	4.8		Sheri	2.9	1.1	3.1	1.9	1.2	2.1	2.0
PrescottOgden	8.0	8.3	6.0	1.9	1.5	1.2	4.5		PrescottOgden	3.6	3.8	2.7	0.8	0.53	0.43	2.0
Sheri	6.3	2.4	6.6	4.2	2.7	4.5	4.4		Pebblewood	2.6	3.1	2.3	1.7	0.5	1.39	1.9
BaileyWashington	4.2	8.9	2.1	2.1	0.0	2.9	3.4		BurningTree	n/a	n/a	n/a	n/a	1.2	2.4	1.8
CoachDrNorth	n/a	n/a	n/a	n/a	0.7	4.9	2.8		BaileyWashington	1.9	3.9	0.9	0.9	0.0	1.3	1.5
BurningTree	n/a	n/a	n/a	n/a	1.6	3.0	2.3		CoachDrNorth	n/a	n/a	n/a	n/a	0.3	2.5	1.4
SpringbookCOD	1.4	n/a	n/a	n/a	1.4	3.3	2.1		SpringbookCOD	0.53	n/a	n/a	n/a	0.52	1.22	0.76

Figures 12 and 13 on the following two pages are maps plotting these same data geographically for the six largest storms expressed by Gallons/LF and Capture Coefficient. Although the use of average RDII severity from the largest six storms tends to smooth out results, in this case only 10 of the 16 meters were installed or produced useable data for the large 17 April 2013 storm. The April storm could be considered a benchmark storm because of the threshold sources of RDII observed (discussed in next section) and this is the only storm that caused surcharge throughout the system. So a basin that has no data from that storm would have a lower average RDII severity than the basins that had data.

To avoid this bias it is prudent to look at RDII severity for the 30 October storm, which is the second largest storm and is the only storm in which all meters provided useable data. Figures 14 and 15 are maps of RDII severity for just the 30 October storm. All four of these RDII severity maps highlight the areas that have undergone sewer rehabilitation and the effect of rehabilitation will be discussed later.

Figure 12 Map of RDII severity in Gallons/LF for the average of the six largest storms.

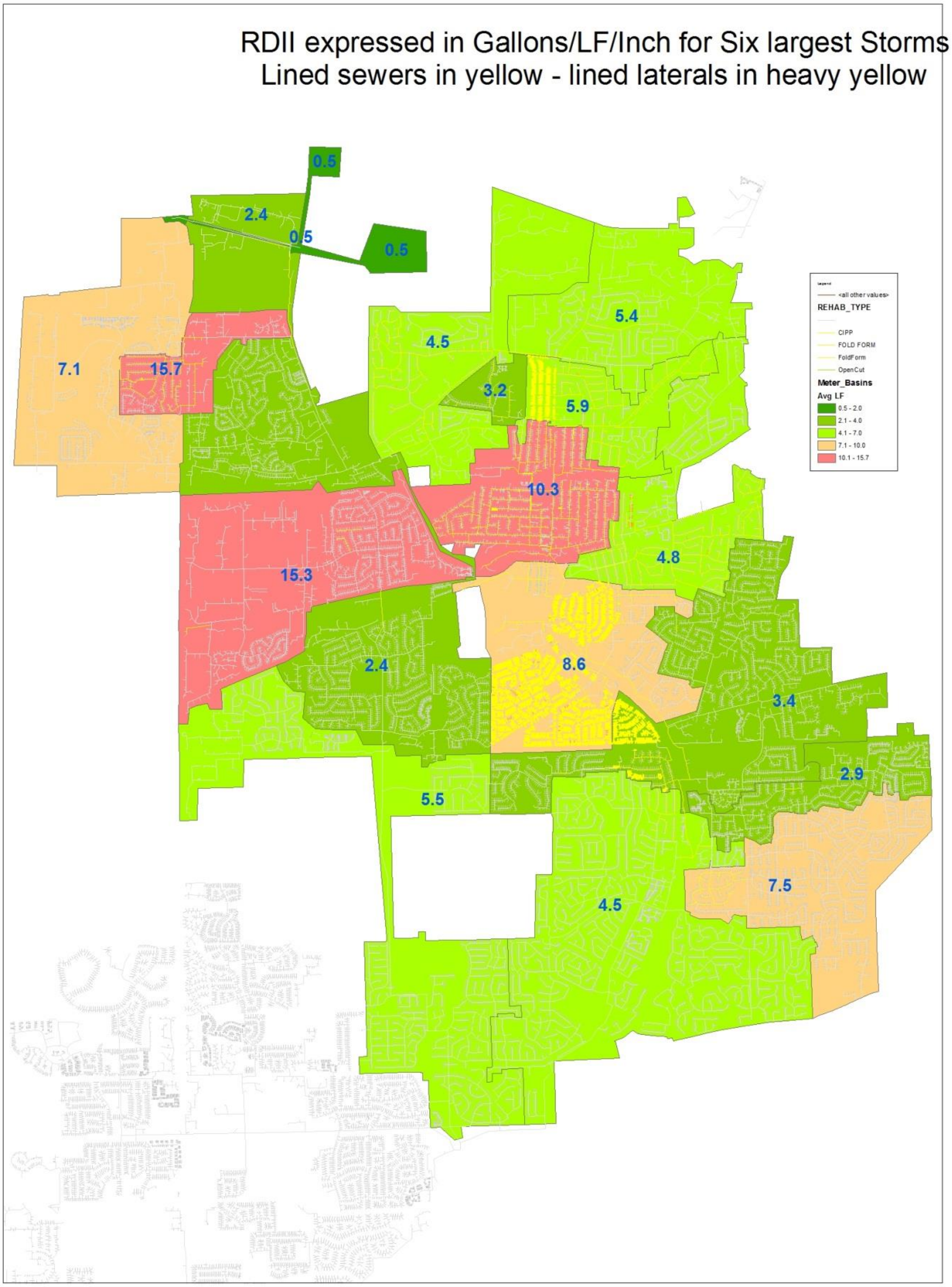


Figure 7 Map of RDII severity expressed as Capture Coefficient (percent of rainfall entering sewers) for six largest storms

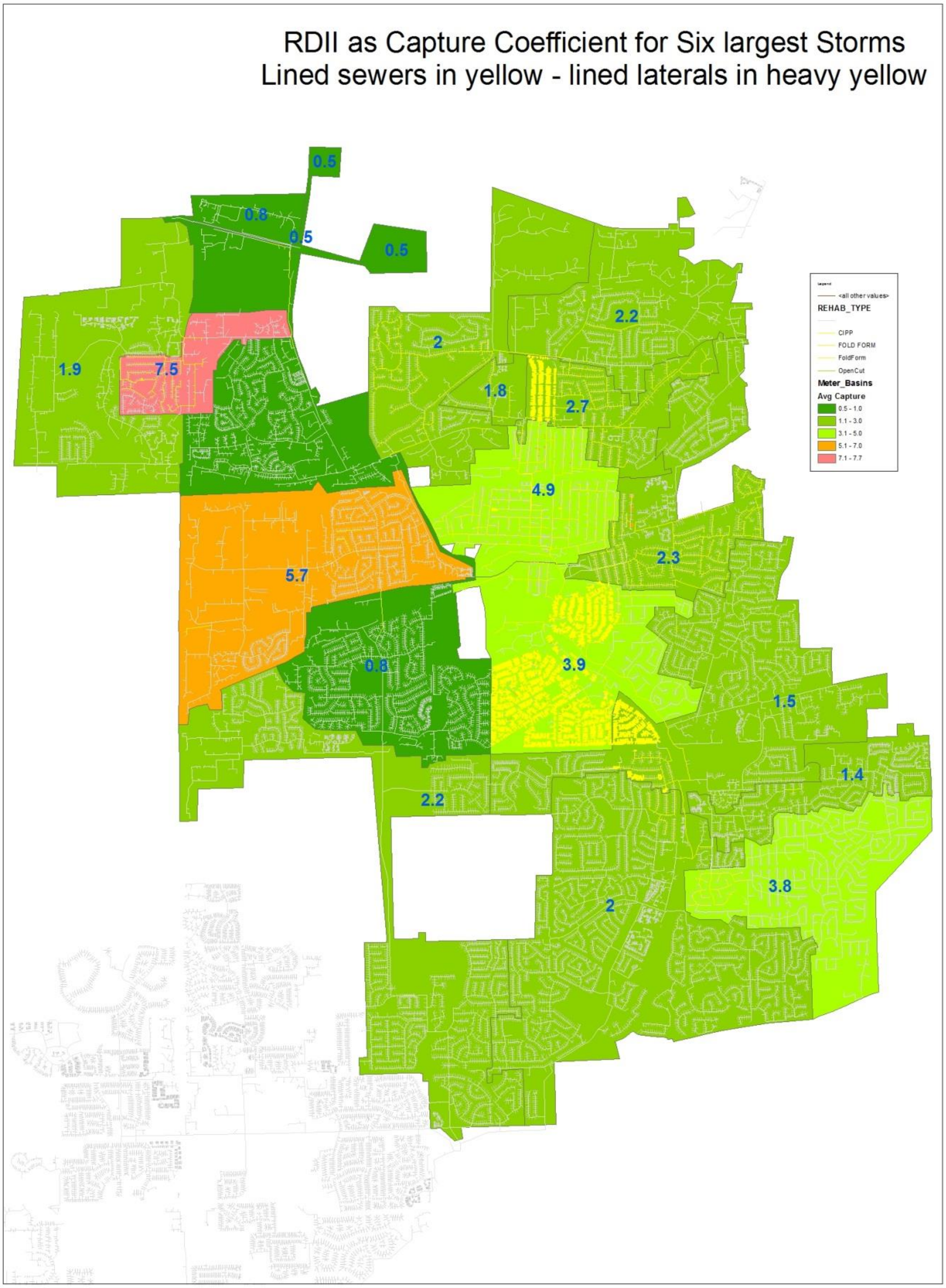


Figure 8 Map of RDII severity for 30 Oct storm in Gallons/LF. Sewers that have undergone rehabilitation are shown in yellow.

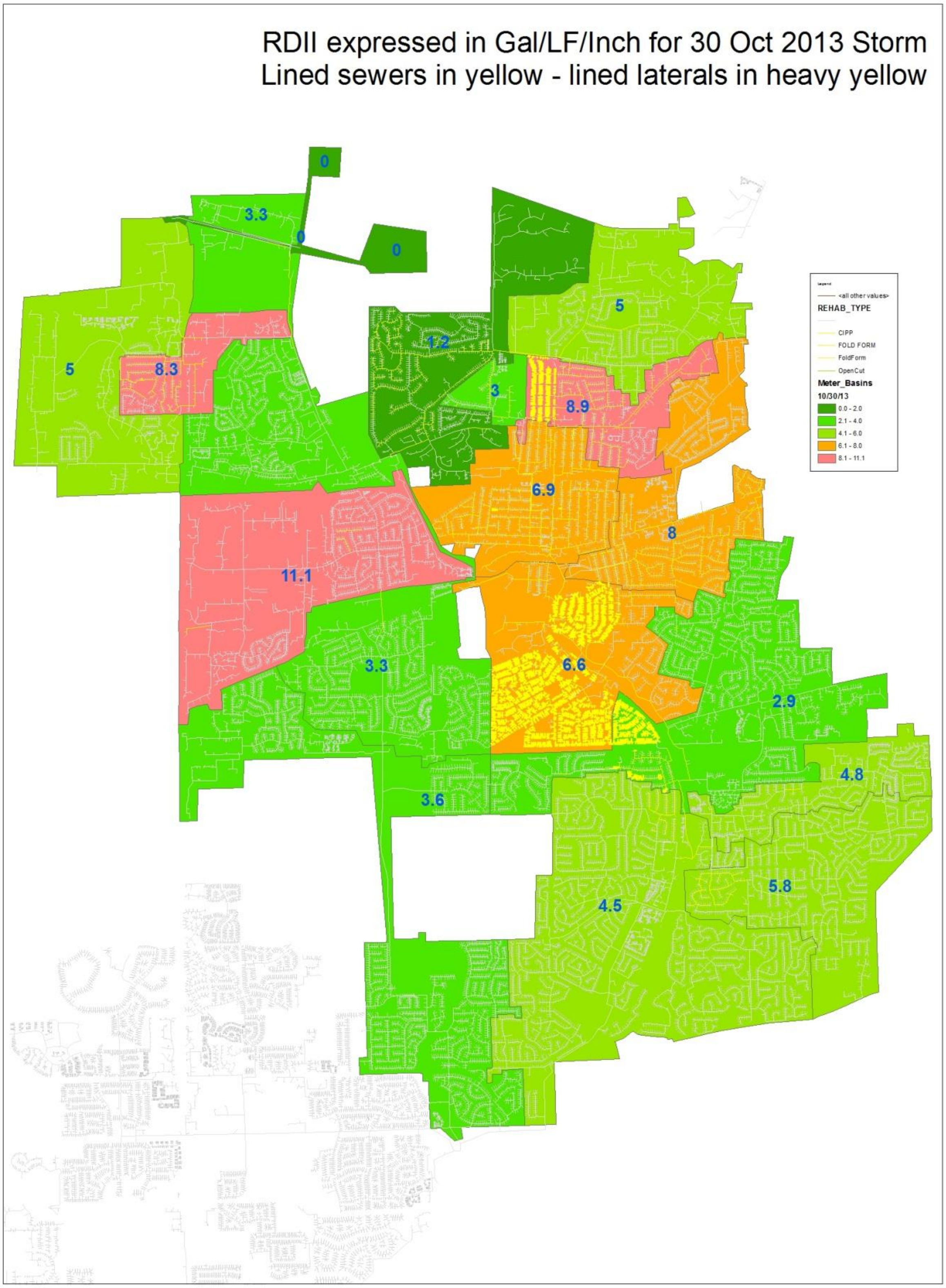
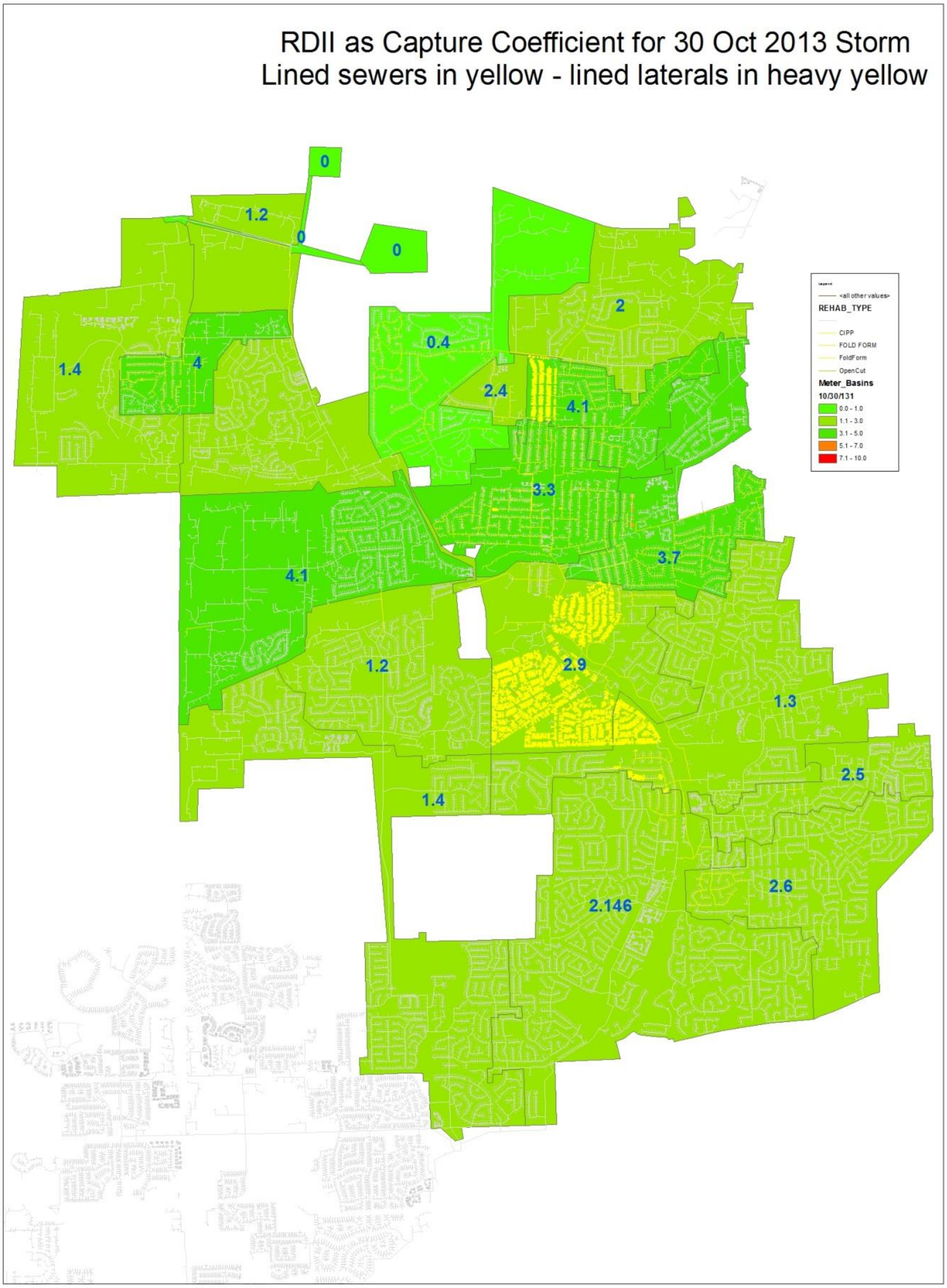


Figure 9 Map of RDII severity for 30 October storm in Capture Coefficient. Sewers that have undergone rehabilitation are in yellow.



Effectiveness of Past Rehabilitation.

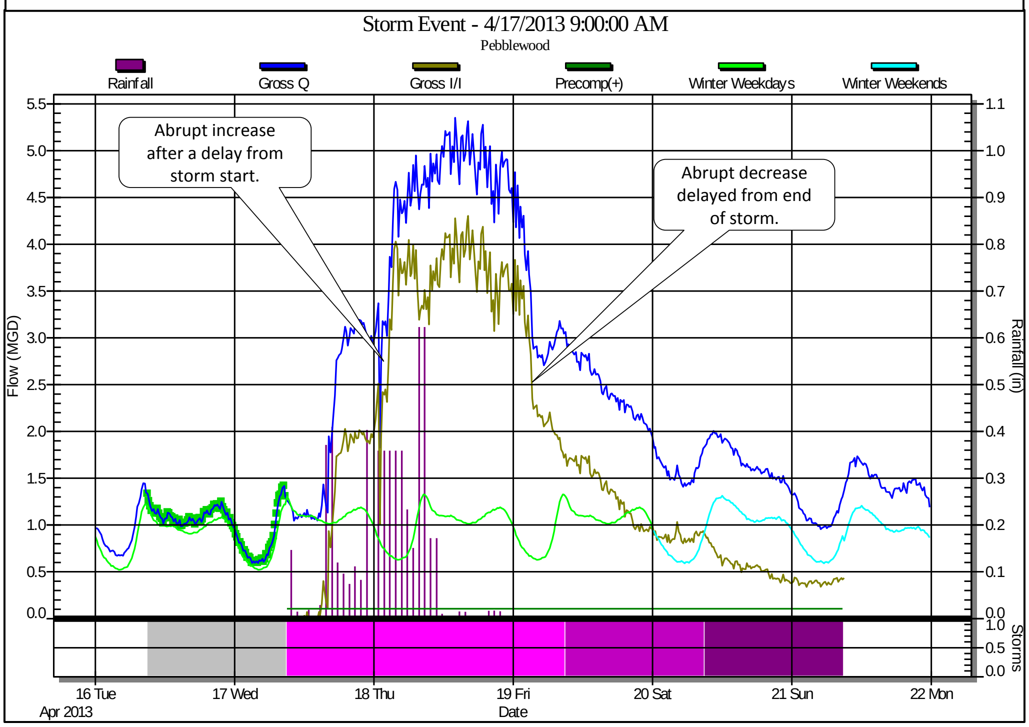
The four maps Figure 9 through 12 showed the sewers and laterals that had previously been rehabilitated. Hobson Mill appears to have undergone extensive rehabilitation of both the public sewer lines and building laterals. Although we do not have pre-rehabilitation data for comparison it is noted the RDII severity of Hobson Mill is at the lower limit of levels that are considered excessive. It is presumed that the Hobson Mills basin was judged to have excessive RDII at one time, hence the rehabilitation effort. Based on this view it also appears that the rehabilitation program was successful. It is also noted that some of the other basins that had some of the public sewers and little or none of the lateral rehabilitated have higher levels of RDII.

2.4 Threshold Sources

Several sewersheds exhibited signs of threshold sources of RDII within the sewershed. A threshold source is one that is activated only after a certain amount of rain has fallen. A simple example of a threshold source is an uncovered manhole on a creek bank. When enough rain causes the creek to rise to the elevation of the MH top, water abruptly spills into the sewer and it ends abruptly when the creek level drops below the MH top. Threshold sources could also be more subtle or not apparent conditions, such as a road-side ditch rising high enough to flood a sewer trench filled with granular and porous backfill. Figure 16 is a hydrograph from Pebblewood during the 17 April 2013 storm exhibiting a threshold source. The delay in the drop gives some indication of what type of source is involved. A short delay suggests a road-side ditch with a long delay suggests a large creek or river.

Only 10 of the 19 meters produced data during the 17 April storm, but this threshold phenomenon was observed at Pebblewood, McDowell (downstream of Pebblewood), Springbrook, Bailey_Washington and Sheri. Appendix A includes the graphics for all sites.

Figure 10 Pebblewood exhibits signs of a threshold source of RDII

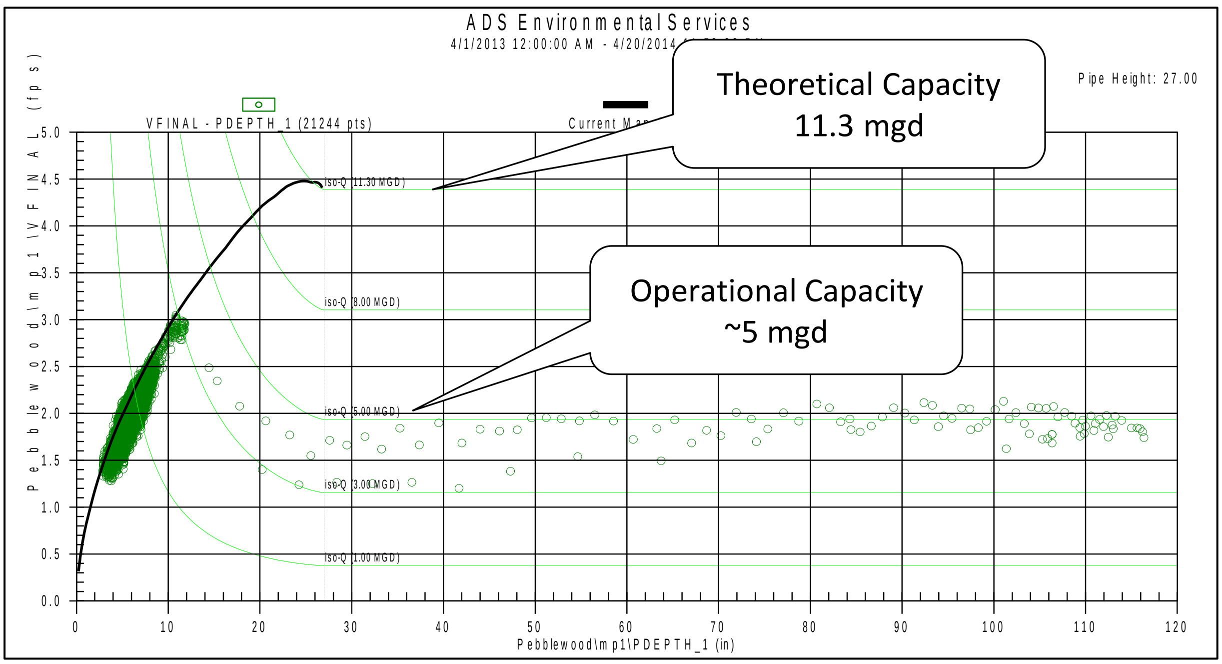


2.5 Operational Capacity

Operational capacity is the actual flow that a pipe can carry as opposed to the theoretical capacity based on pipe slope and roughness of the pipe. The technique for this analysis is to look at depth-velocity scattergraphs on which are plotted with the Manning Pipe curve and Iso-Q lines. Figure 17 is a scattergraph using the Profile entity Pdepth and Vfinal for Pebblewood.

What is observed here is that the theoretical capacity, as established by the Manning curve is around 11.3 mgd. However the actual data show that the sewer enters backwater at around 12 inches of depth and the Operational capacity is actually around 5 mgd as the pipe fills and surcharges to 116 inches. This sewer is carrying half its capacity.

Figure 17 Scattergraph of Pebblewood showing that Operational Capacity is around half of its theoretical capacity.



The following Figures 18 and 19 are scattergraphs for the 12 meters that were in operation in April 2013. The scattergraphs include the Manning curve that was fit to valid data and Iso-Q lines which are lines of constant flow rate. These lines are similar to elevation contour lines on a topographic map. The approximate Operational Capacity can be determined by comparing the measured flow at full pipe to the flow rate at the top of the Manning pipe curve. Notable observations are included on each graphic.

Figure 11 Scattergraphs showing Operational Capacity.

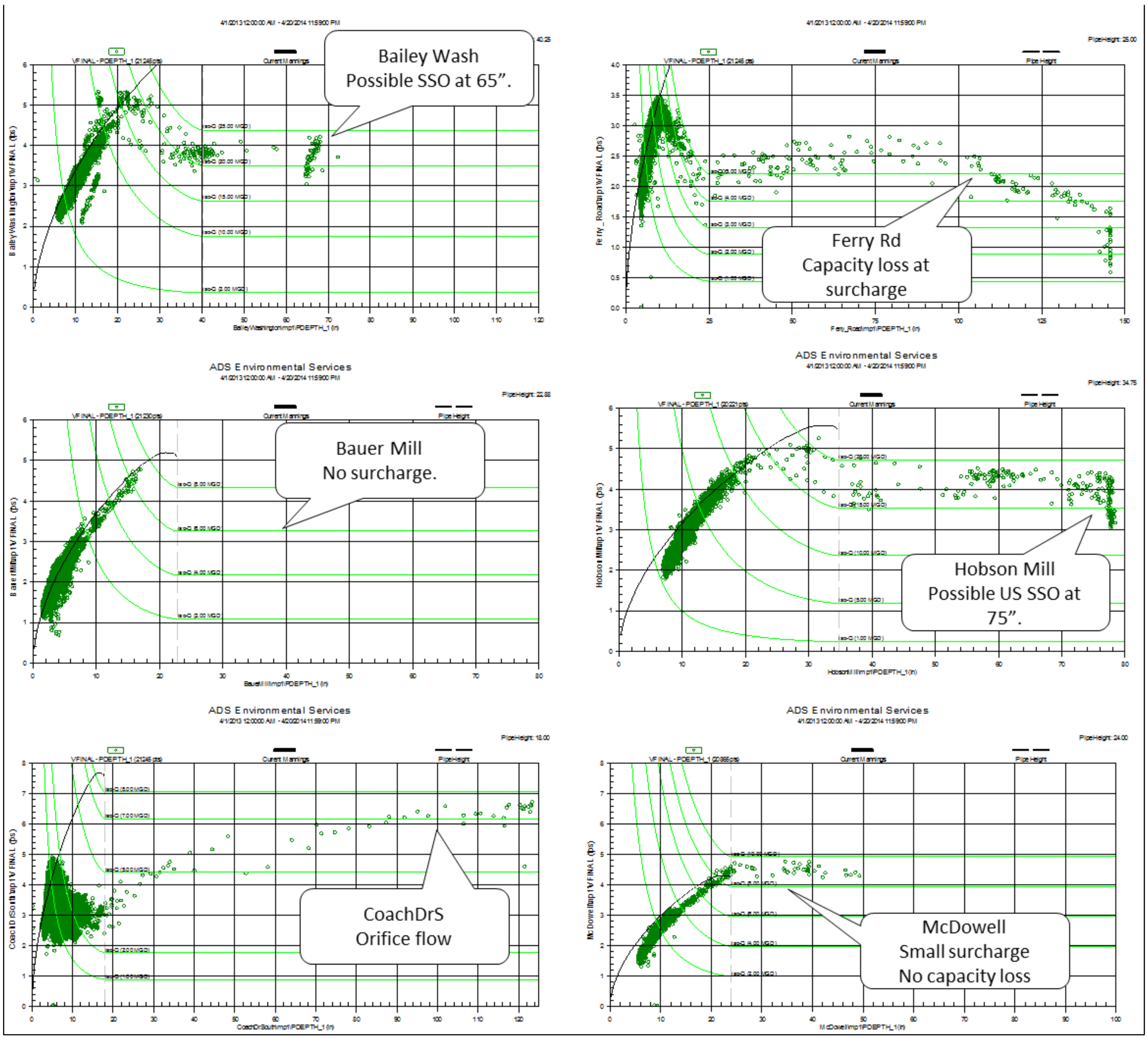
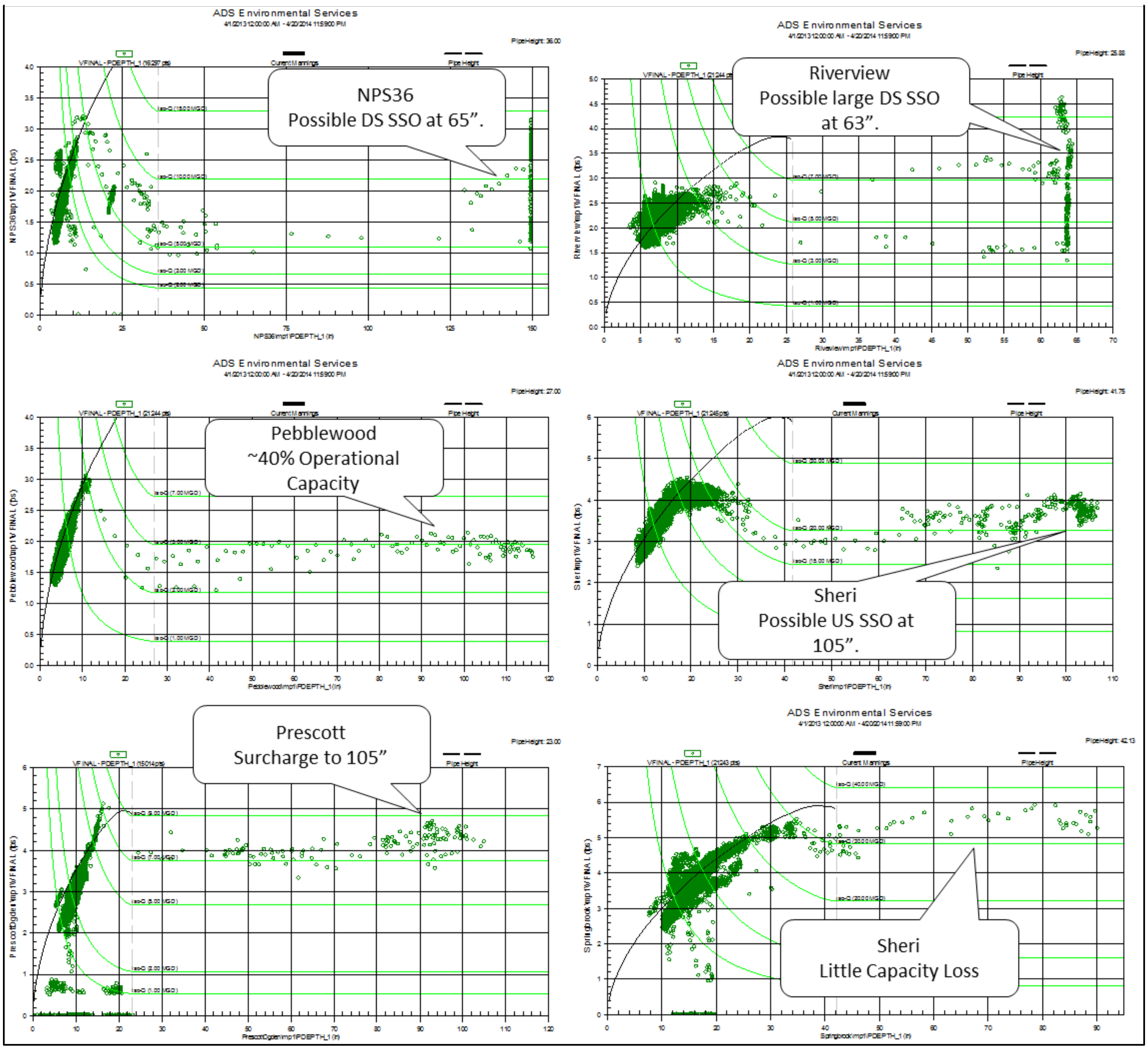


Figure 12 Scattergraphs showing Operational Capacity.



3.0 – Conclusions

Even though these sewershed are fairly large, there is a significant difference in RDII severity among them. Based on the rankings for RDII expressed both as Gallons/LF/Inch and Capture Coefficient, McDowell, NPS36 and Riverview basins exceed the general rules of thumb for excessive RDII. Pebblewood is lower than the level of excessive RDII, but it did exhibit a threshold source of RDII that could move it into the excessive category in heavier rains. Only 10 of 16 meters were operational during the 17 April storm so other basins could suffer from threshold sources and have not detected it.

It appears that the City's program of sewer line and lateral rehabilitation has been effective. It is commonly observed by engineers and collection system managers, that RDII reduction is 'moderate' when only the public sewer line and manholes are rehabilitated. It is not until there is comprehensive rehabilitation of both the public sewers and laterals that higher levels of reduction are achieved. The extensive sewer and lateral rehabilitation in Hobson Mills likely is the reason that current RDII severity is at the lower limit of severity that is considered excessive.

The temptation is to assume that the RDII problems worth trying to fix are in only the sewersheds with the most severe RDII, however large sewersheds tend to mask both good and bad sections of the sewer. A long term program of mini-basin metering within each of the larger sewersheds will help refine the sewers that need to be rehabilitated/replaced. It has been demonstrated that the majority of RDII originates from a minority of the system. Many believe RDII sources adhere to the 80/20 rule that 80% of RDII enters from 20% of the system. This phenomenon is not observable until RDII is measured in small meter basins in the range of 10,000 LF per meter basin or less. The isolation of RDII into smaller portions of the system allows for RDII reduction to be achieved at a much lower cost.

Several meters recorded significant capacity loss in the downstream sewers. A good example is the Pebblewood meter which shows that the 11 mgd sewer can convey only 5 mgd when full. Yet the downstream McDowell sewer is not restricted and can convey the sewer's entire 9 mgd capacity. It is recognized that this analysis is at only 19 points in the system.

3.1 – Recommendations

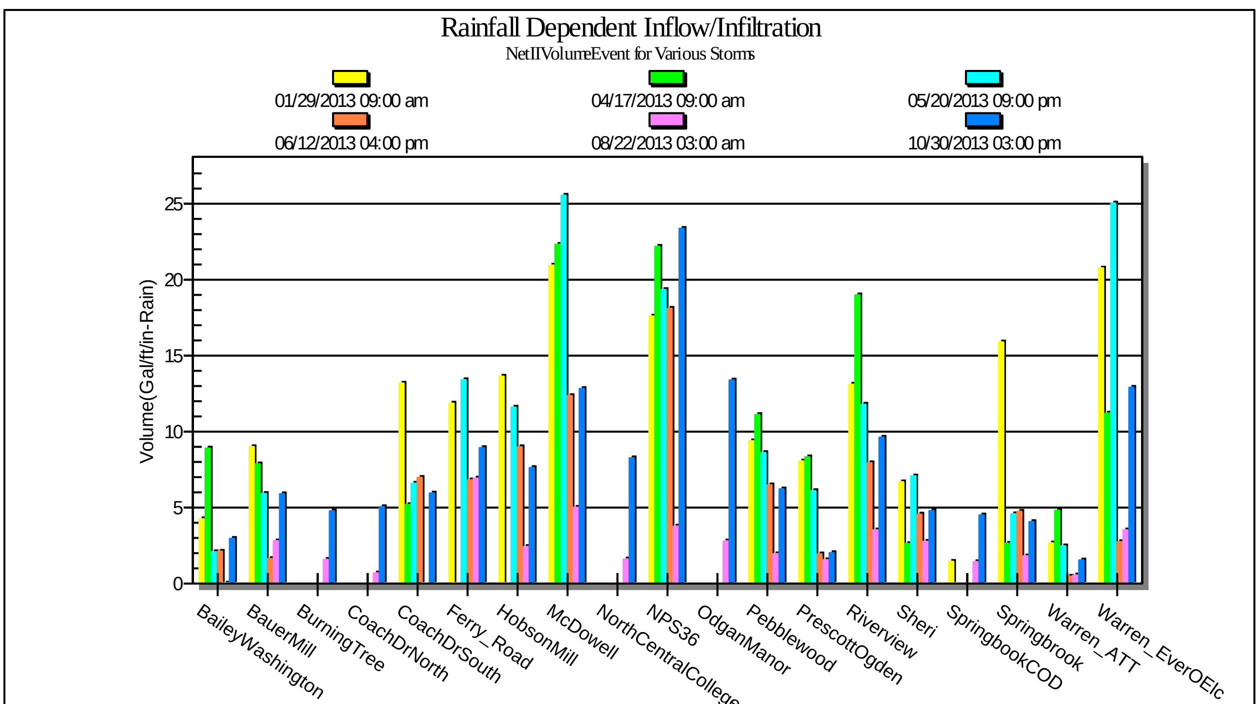
Implement a mini-basin program that sub-divides the current large sewersheds into mini-basins of approximately 10,000 LF. The metering should last for 6 months or a year to capture as much data as possible. Over time the program can work its way through the top 3 or 4 of the worst-performing sewershed in this study. This RDII analysis can be repeated at the end of each metering cycle to identify the sections of the system that require rehabilitation.

Modify the data handling procedure to combine ultrasonic and pressure depths into the single Dfinal entity. This achieves greater accuracy in partially-full pipe and makes it easier to understand how the system performs during surcharge. Operational capacity is easier to understand as well.

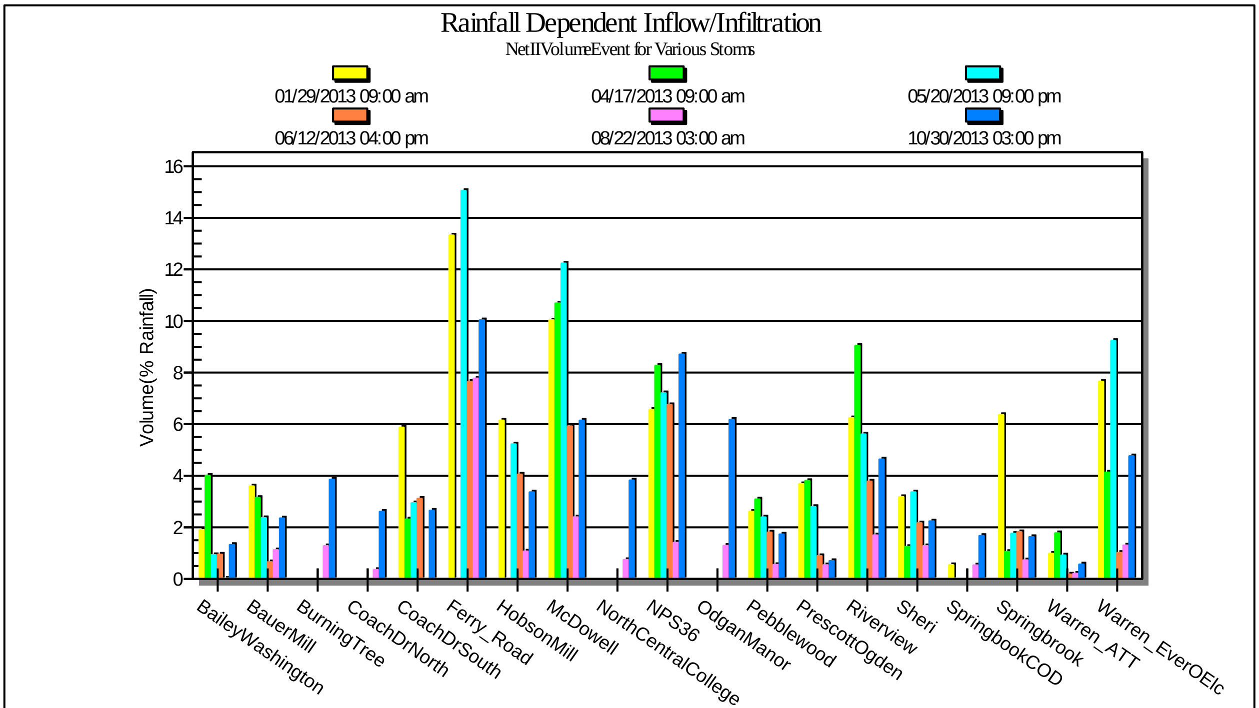
Appendix and Graphics

These bar graphs display all RDII data for all 19 meters normalized by LF and Capture Coefficient for the six largest storms. The Ferry Road site and the two Warrenville sites were not included the ranking the main body of the report because proper basin size information was not available.

Although there are no hard and fast rules for judging severity of RDII using these parameter, a good rule of thumb is that values greater than 7 - 10 Gal/LF/Inch, are often considered to be excessive. Capture Coefficient values greater than 5% are often considered to be excessive. Variables that modify this rule of thumb are antecedent rainfall, accuracy of LF measurements, accuracy of area measurement, the season of the year and accuracy of rainfall measurements. Large basins inherently will be biased low in Capture Coefficients because large basin necessarily include un-sewered areas such as parks, cemeteries, soccer fields and other such land uses. Such areas increase acreage, but do not contribute to RDII values.



Basin	BaileyWashington	BauerMill	BurningTree	CoachDrNorth	CoachDrSouth	Ferry_Road	HobsonMill	McDowell	NorthCentralCollege	NPS36	OdganManor	Pebblewood	PrescottOgden	Riverview	Sheri	SpringbookCOD	Springbrook	Warren_ATT	Warren_EverOElc
01/29/2013 09:00 am	4.2	9.0			13.2	11.9	13.6	20.9		17.6		9.4	8.0	13.1	6.7	1.4	15.9	2.6	20.7
04/17/2013 09:00 am	8.9	7.9			5.2			22.3		22.2		11.1	8.3	19.0	2.6		2.6	4.8	11.2
05/20/2013 09:00 pm	2.1	5.9			6.6	13.4	11.6	25.5		19.3		8.6	6.1	11.8	7.1		4.6	2.5	25.0
06/12/2013 04:00 pm	2.1	1.6			7.0	6.8	9.0	12.4		18.1		6.5	1.9	7.9	4.5		4.7	0.5	2.7
08/22/2013 03:00 am	0.0	2.8	1.6	0.7		6.9	2.4	5.0	1.6	3.8	2.8	1.9	1.5	3.5	2.8	1.4	1.8	0.5	3.5
10/30/2013 03:00 pm	2.9	5.9	4.8	5.0	5.9	8.9	7.6	12.8	8.3	23.4	13.4	6.2	2.0	9.6	4.8	4.5	4.1	1.5	12.9



Basin	BaileyWashington	BauerMill	BurningTree	CoachDrNorth	CoachDrSouth	Ferry_Road	HobsonMill	McDowell	NorthCentralCollege	NPS36	OdganManor	Pebblewood	PrescottOgden	Riverview	Sheri	SpringbookCOD	Springbrook	Warren_ATT	Warren_EverOElc
01/29/2013 09:00 am	1.9	3.6			5.9	13.3	6.1	10.0		6.6		2.6	3.7	6.2	3.2	0.5	6.4	1.0	7.6
04/17/2013 09:00 am	4.0	3.1			2.3			10.7		8.3		3.1	3.8	9.0	1.2		1.0	1.8	4.1
05/20/2013 09:00 pm	0.9	2.4			2.9	15.0	5.2	12.2		7.2		2.4	2.8	5.6	3.4		1.7	0.9	9.2
06/12/2013 04:00 pm	0.9	0.6			3.1	7.6	4.0	5.9		6.7		1.8	0.9	3.8	2.2		1.8	0.2	1.0
08/22/2013 03:00 am	0.0	1.1	1.3	0.3		7.8	1.1	2.4	0.7	1.4	1.3	0.5	0.5	1.7	1.3	0.5	0.7	0.2	1.3
10/30/2013 03:00 pm	1.3	2.3	3.9	2.6	2.6	10.0	3.4	6.1	3.8	8.7	6.2	1.7	0.7	4.6	2.2	1.7	1.6	0.6	4.8

END OF REPORT